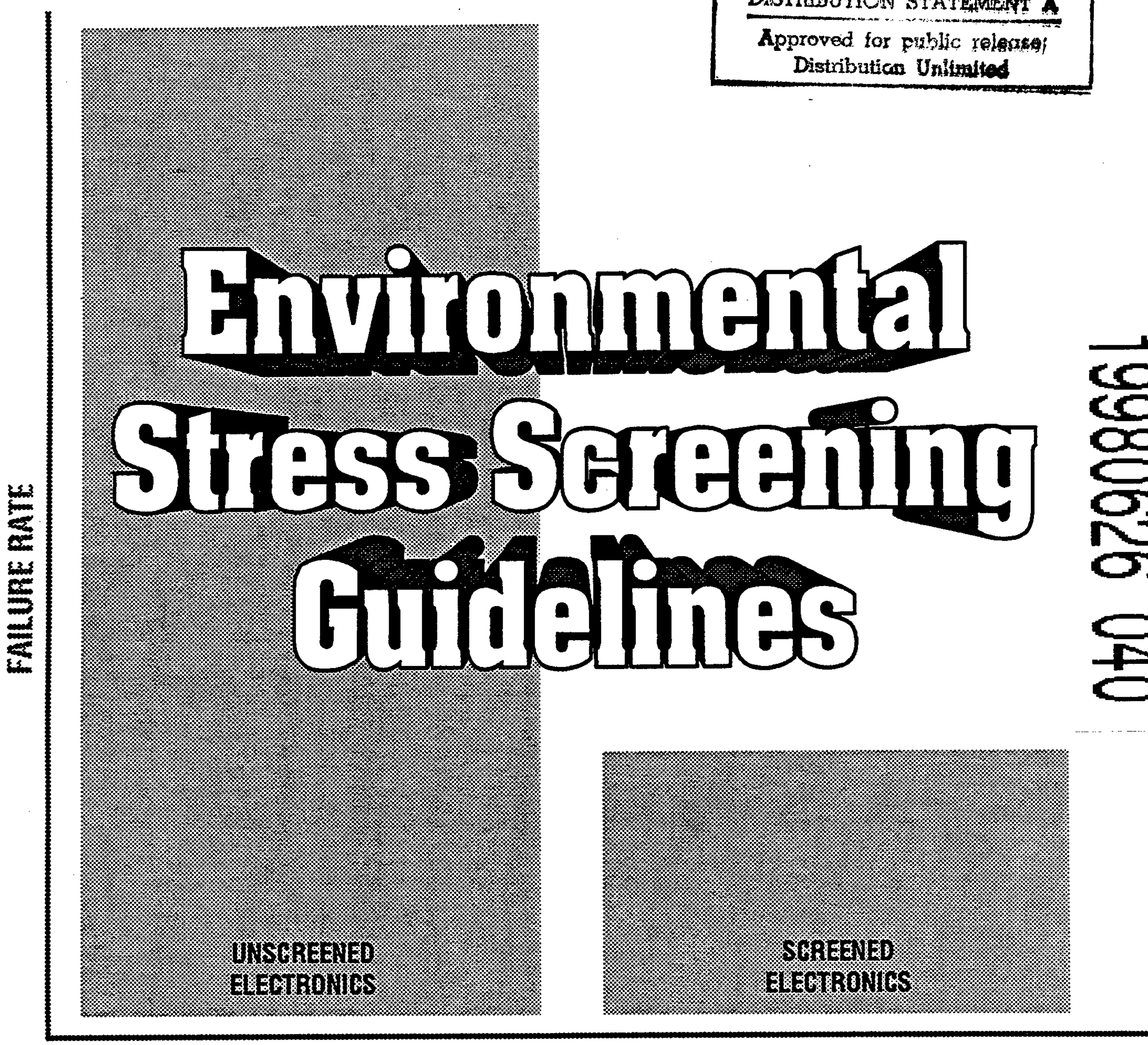
Environmental Stress Screening Guidelines



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TRI-SERVICE TECHNICAL BRIEF 002-93-08

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WASHINGTON, DC 20352

USAF: SAF/AQK
1060 AIR FORCE PENTAGON
WASHINGTON, DC 20330-1060

TRI-SERVICE TECHNICAL BRIEF 002-93-08

TRI-SERVICE ENVIRONMENTAL STRESS SCREENING GUIDELINES

JULY 1993

PREFACE

Our urgent requirements to improve the operational performance of weapon systems while reducing their operating and support costs can be met only by improving their quality and reliability. Environmental stress screening (ESS) has been shown to be a significant aid towards meeting these objectives.

This document is the culmination of work that began in the mid-1980s when industry, with Government encouragement, initiated the revision and improvement of existing Government ESS guidelines. The Departments of the Army, Navy, and Air Force have collaborated in its preparation. It provides guidance for implementing the ESS requirements in DoD Instruction 5000.2, encouraging consistency in interpretation among all three services.

By providing a single source of ESS management methods, engineering guidance, best practices and issues to be considered in preparing contracts, this document will help program managers, project engineers, and contracting officers implement a successful environmental stress screening program. We encourage you to use it.

LLOYD K. MOSEMANN, II
Deputy Assistant Secretary
(Communications, Computers, and Support Systems)
Office of the Assistant Secretary of the Air Force (Acquisition)

W. J. WILLOUGHBY, JR.
Director, Product Integrity
Office of the Assistant Secretary of the Navy
(Research, Development and Acquisition)

STEPHEN R. BURDT
Director for Program Evaluation
Office of the Assistant Secretary of the Army
(Research, Development and Acquisition)

ACKNOWLEDGMENTS

TRI-SERVICE COMMITTEE ON ENVIRONMENTAL STRESS SCREENING

Douglas O. Patterson	U. S. Navy	OASN(RD&A)PI	Chairman
Louis C. Gills	U. S. Navy	OASN(RD&A)PI	
MAJ Kevin Kirlin	U. S. Air Force	SAF/AQXM	
Dr. Pat Larter	U. S. Air Force	SM-ALC	
Bobby G. Whiteley	U. S. Army	AMCRD-1C	
Frank DiGiovanni	U. S. Army	CECOM	

INSTITUTE OF ENVIRONMENTAL SCIENCES
ENVIRONMENTAL STRESS SCREENING OF ELECTRONIC HARDWARE
DOCUMENT REVIEW WORKING GROUP

Michael W. Gust	Mitre Corporation	Bedford, MA	Chairman
Henry J. Caruso	Westinghouse Electric Corporation	Baltimore, MD	
Jack Dunn	Mitre Corporation	Bedford, MA	
Dr. Pat Larter	U. S. Air Force	Colorado Springs, CO	
C. E. Mandel, Jr.	Consultant	Laguna Hills, CA	
Arthur A. McGill	Lockheed Missiles and Space Company	Sunnyvale, CA	
George Miller	Naval Air Warfare Center	Indianapolis, IN	
Michael A. Roy	Westinghouse Electric Corporation	Baltimore, MD	
Edward A. Szymkowiak	Westinghouse Electric Corporation	Baltimore, MD	
Doug Allison	Litton Guidance and Control Systems	Woodland Hills, CA	
Rudy S. Cazanjian	GTE Government Systems	Mountain View, CA	
James R. Marano	Alliant Techsystems	Hopkins, MN	

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SECTION 1
INTRODUCTION

1.1 PURPOSE & SCOPE

Environmental stress screening (ESS) is a cost-effective means of improving quality and reliability of electrical, electronic, electro-optical, electromechanical and electrochemical assemblies and systems at a time when defect removal is relatively inexpensive. This document provides guidance for implementing the ESS requirements in Part 6, Section C, Paragraph 3f(1) of DoD Instruction 5000.2 dated 23 February 1991. It will help program managers, project engineers, and contracting officers implement a successful ESS program. It explains to management the benefits of ESS, and when and how to implement it, and conveys ESS fundamentals, planning and execution to engineers. It focuses on ESS in development, production and overhaul, at levels of assembly from the printed wiring assembly to the system. ESS of parts is covered in other publications.

Random vibration and temperature cycling have proven to be the most successful forms of ESS in terms of effective flaw precipitation. The focus of these guidelines is on these forms, and an acceptable methodology for each is detailed herein and recommended for use. Other forms of ESS which may prove effective for specific hardware configurations and characteristics will require approval by the procuring agency.

1.2 BACKGROUND

The Department of Defense and its contractors have made great strides in recent years in learning how to design reliable weapon systems. Most failures in fielded systems today are traced to defective parts and improper workmanship during manufacturing.

In the 1950s, in order to reduce rework due to defective parts, functional testing of incoming parts was introduced. Because of the initial high failure rate experienced by equipment due to infant mortality of parts, burn-in at higher levels of assembly was instituted in the 1960s. None of these approaches, however, stressed the assemblies adequately to precipitate manufacturing defects. ESS was introduced in the 1970s to stimulate the identification of latent defects as early in the production process as possible and to correct the process to preclude their recurrence.

Each Service independently developed regulations and guidance on implementing ESS in their acquisitions. Among companies making products for tri-service use, this led to conflicts and confusion, increased acquisition costs through inefficient utilization of ESS screening equipment, increased configuration control efforts, and more complex logistics systems.

The Departments of the Army, Navy, and Air Force have collaborated in the preparation of this document to resolve this problem. By offering a single source of ESS management methods, engineering guidance, best practices and issues to be considered in preparing Statements of Work and contracts, this document will help to assure consistency in interpretation and implementation of ESS programs across all three Services.

1.3 DOCUMENT PREPARATION

The Tri-Service Environmental Stress Screening Guidelines acknowledges the Institute of Environmental Sciences (IES) and the Environmental Stress Screening of Electronic Hardware (ESSEH) Committee for their comments and for use of published information presented in the IES-ESSEH *Environmental Stress Screening Guidelines for Assemblies* dated March 1990. Major portions of the ESSEH Guidelines have been reprinted with permission from the IES. These guidelines have been developed by the ESSEH Technical Committee of the IES as a continuing series to advance the state of technical and engineering sciences.

SECTION 2
PROGRAM MANAGEMENT GUIDANCE

The purpose of this section is to assist program managers in understanding the issues and implementing environmental stress screening. Contracting specialists will also find this section useful in integrating and implementing ESS as a part of the acquisition strategy.

2.1 WHAT IS ENVIRONMENTAL STRESS SCREENING?

A clear understanding of environmental stress screening requires a good definition as a baseline. The following definition addresses the key aspects of ESS:

Environmental stress screening of a product is a process which involves the application of one or more specific types of environmental stresses for the purpose of precipitating to hard failure, latent, intermittent, or incipient defects or flaws which would cause product failure in the use environment. The stress may be applied in combination or in sequence on an accelerated basis but within product design capabilities.

ESS isolates manufacturing problems caused by poor workmanship, faulty and/or marginal parts. It also identifies design problems if the design is inherently fragile and if qualification and reliability growth tests are too benign. The most common stimuli used in ESS are temperature cycling and random vibration.

ESS is a process rather than a test in the normal accept/reject sense. Those participating in the effort, including the contractor, should never be led to believe that a "failure" is bad and would be held against them. *ESS is intended to stimulate defects*, not to simulate the operating environment, and therefore, factory "failures" are encouraged.

The root causes of ESS failures need to be found and corrected before there is a complete process.

Initially, ESS must be applied to 100% of the units manufactured, including repaired units. By using a closed loop feedback system, one will be able to eventually determine if the screening program should be modified.

A viable ESS program must be dynamic—the screening program must be actively managed, and tailored to the particular characteristics of the equipment being screened. This includes conducting a survey to determine the mechanical and thermal characteristics of the equipment and refining the screening profiles as more information becomes available and/or designs, processes, and circumstances evolve.

2.2 WHERE IS ESS APPLICABLE?

Best design and manufacturing practice calls for the application of environmental stress screening to:

- All material acquisitions that include electrical, electronic, electro-optical, electromechanical or electrochemical components in demonstration & validation, engineering & manufacturing development and production phases
- Reprocurements and the procurement of spare and repair parts where the cost of ESS implementation can be amortized economically or where ESS was required in original equipment
- Depot overhaul programs where opportunities exist for substantial cost savings and overhaul/ repair effectiveness
- Nondevelopmental items, such as commercial off-the-shelf (NDI-COTS) and domestic or foreign military (NDI-Military) items only to the extent ESS was implemented and documented during either current or previous production. NDI items are not to be used unless they comply with all specified requirements, including ESS.
- Equipment and spares that have been specifically designated to receive ESS

ESS may be applied at any manufacturing level, from piece parts to end items. It is intended to screen defects in a manner that is not harmful to properly manufactured material. Some components, such as plasma displays, vacuum tubes, etc., by nature of their design, are not amenable to either vibration or temperature screening. Hardware proven to be too fragile

may be excluded, but rationale for exclusion must be approved by the government.

2.3 BENEFITS OF ENVIRONMENTAL STRESS SCREENING

Proper application of environmental stress screening offers several benefits:

- Reduced overall life cycle cost
- On-time deliveries
- Improved reliability after delivery
- Improved user confidence and/or satisfaction
- Reduced support costs
- Improved readiness
- Improved production process

While these benefits far outweigh the costs of implementation, they do not come without a penalty. ESS must be implemented early in the program and closely supervised throughout. It will take time and commitment of the senior managers, because the benefits are long term but the requirements for people and funds occur early in the program.

ESS is normally conducted during the manufacturing process to detect latent defects in parts and workmanship, but may also disclose design limitations that were not detected during qualification and engineering tests. In addition, there are distinct benefits to conducting ESS during development as well. A considerable percentage of the failures encountered during a reliability growth (test, analyze and fix) test program may be caused by poor workmanship and defective parts. These non-design-related failures can mask design-related failures, can cause schedule slippage, and can adversely affect performance. By screening the item prior to this testing, these adverse effects can be minimized. It is virtually impossible to achieve design reliability without reducing to a minimum the reliability degradation due to screenable flaws. Additional benefits are presented in Table 2-1.

2.4 PLANNING CONSIDERATIONS

It is imperative that ESS resources, training requirements, and detailed plans (including levels of assembly and defined profiles) are in place when production begins. Therefore, it is desirable to reach this state during engineering & manufacturing development, so that hardware for qualification and reliability growth testing is of higher quality and can be screened (to prevent failures that are not design related). This implies that experimentation and planning should begin early.

The cost of rework in manufacturing escalates by orders of magnitude as the assembly process proceeds from piece part level to printed wiring assembly/module, unit, system, and to the user. Finding defects at the lowest possible level of assembly will tend to minimize rework costs by reducing corrective action time. However, some flaw types manifest themselves only at the higher levels of assembly. Tailoring the screen by means of the vibration and thermal characteristics of the hardware coupled with defect population at each level of assembly is essential.

This document presents many management and technical details to be considered and some of the trade-off decisions that will vary with specific programs. The guidance presented may be limited in some areas but there is no intent to make this a textbook on the many facets of ESS. Because of the obvious cost, schedule and performance impacts relative to the ESS decisions, both government and contractor program managers must not treat their decisions lightly. Where the required ESS expertise is not available or will not be in time to address these issues, ESS consultants may need to be considered. Each service has at least one organization which specializes in ESS engineering and the Institute of Environmental Sciences has published many appropriate articles in addition to those listed in Appendix B.

2.5 MANAGEMENT ISSUES

The following ESS management issues and guidance need to be considered to increase the probability of implementing a viable ESS program:

- How critical are the items proposed for ESS and what level of quality is required? Criticality would be high if a failure of the item results in high probability of loss of life or an inability to complete a mission, high life cycle cost, or high cost of failure.

TABLE 2-1. ESS BENEFITS TO MANAGEMENT

	MANAGEMENT TARGET	BENEFITS/RATIONALE
ENGINEERING & MANUFACTURING DEVELOPMENT	PROGRAM MANAGER AND ENGINEERING MANAGER	• ENSURES HARDWARE PERFORMANCE ON DEMAND • CONTRIBUTES TO PARTS LIST DEVELOPMENT • IMPROVES RELIABILITY GROWTH TESTING • ASSURES READINESS OF PRODUCTION SCREENS • ESS WEEDS OUT PROBLEM VENDORS • 60% FAILURES ARE DUE TO WORKMANSHIP DEFECTS • 30% FAILURES ARE DUE TO PART FLAWS • ESS DESIGN IS BY NATURE ITERATIVE
PRODUCTION	MANUFACTURING MANAGER	• REDUCES REWORK COST • MINIMIZES SCHEDULE DELAYS • FACILITATES ACHIEVEMENT OF DESIGN RELIABILITY IN PRODUCTION HARDWARE • IMPROVES PRODUCTIVITY • REDUCES OR ELIMINATES WORKMANSHIP AND PART DEFECTS • ENTIRE PRODUCTION PROCESS MORE EFFICIENT • DEFECTS SURFACED AT LOWEST LEVELS OF ASSEMBLY AND ROOT CAUSE CORRECTIVE ACTION IMPLEMENTED • ACCEPTANCE TEST PASSED ON FIRST PASS, LESS HIGH ASSEMBLY LEVEL REWORK
GENERAL		• LESS PROGRAM COST • LESS SCHEDULE AND VARIANCE IMPACT • HIGHER FIELD RELIABILITY • FAILURES ARE FORCED TO EMERGE AT CONVENIENT PRODUCTION STEPS • LESS LATENT DEFECTS SHIPPED TO FIELD
USER		• INITIALLY DELIVERED HARDWARE MEETS RELIABILITY AND QUALITY REQUIREMENTS • LOWERS SUPPORT COST • LOWERS LIFE CYCLE COST • SPARES MEET RELIABILITY REQUIREMENTS • ON-TIME DELIVERIES • INCREASES CONFIDENCE AND SATISFACTION • REMOVES DEFECTS NORMALLY PRESENT IN DELIVERED HARDWARE • FEWER FIELD FAILURES OR MAINTENANCE ACTIONS • ESS INFLUENCES THROUGHOUT ACQUISITION CYCLE

- The quantity to be procured should be considered. Where small quantities are involved and the item does not qualify as a high criticality item as given above, then it may be cost effective to use only the relatively low cost thermal cycling screens.
- The tailoring and optimization processes described in this document may result in stress levels or other ESS parameters that are less than those of the baseline provided in Tables 3-3 and 3-4. In all cases, appropriate rationale and data should be presented to justify the ESS conditions to be applied.
- The type of random vibration should be considered. Should true random vibration excitation or a

low cost alternative such as quasi-random (pneumatic) vibration excitation be used for the detection of flaws?

- The contractor's proposed ESS program plan should emphasize the following:
  - Commitment to and understanding of ESS
  - Failure reporting and corrective action system (FRACAS). A FRACAS should be in place and operating.
  - Span of control for ESS. If ESS is being performed by multiple subcontractors, what is their degree of implementation?
  - Planned ESS profile optimization technique. The Services recommend one of four random vibration techniques, and one of two thermal cycling techniques. Each has both advantages and disadvantages.
  - Managerial and technical approaches to ESS. The plan should include proposed methods for determining initial screening environment, applicable assembly levels, data collection, failure analysis and corrective action, and procedures or methods to be used in altering the program.
  - Nondevelopment items (NDI), such as commercial off-the-shelf and domestic or foreign military items, if those items have been determined to meet government requirements
- The Government program manager should also address the following additional issues:
  - ESS profile requirements should not be specified in the RFP. In general, it is better to allow contractors to propose an ESS profile than to specify a particular profile, unless the contract is a reprocurement and the original profile holding fixtures, vibration machine and chamber capabilities are contained or referenced on the drawings and are found to be satisfactory. (Note: the original profile may have to be modified due to changes in the production process and component manufacturing variability.)
  - The ESS and quality history of the contractor

2.6 PROGRAM MANAGEMENT CHECKLIST

The following checklist should be used in the development of a management plan for implementing ESS in each phase of the acquisition process:

DEMONSTRATION & VALIDATION

- Establish adequate ESS funding. To facilitate this, a cost/benefit analysis should be conducted to justify funding. The basis of this analysis could be the development of a historical data base on costs to implement various screens versus return on investment (cost avoidance).
- Assess the training needs of ESS personnel and develop a plan to correct any identified training and/or qualification deficiencies.
- Determine equipment availability, adequacy, capacity, etc., to perform the intended screens.
- Identify special long lead equipment requirements (e.g., fixtures, racks, etc.).
- Determine appropriate initial profile.
- Establish a FRACAS to report and analyze faults that are precipitated out during screening.

ENGINEERING & MANUFACTURING DEVELOPMENT

- Continue to tailor, refine, and evaluate the adequacy of the ESS profile, striving for an optimum screen. The absence of fault precipitation during initial production or reprocurement may be an indication of a weak screen that needs further optimization.
- Establish or continue a closed-loop FRACAS to report and analyze faults that are precipitated out during screening.
- If a test-analyze-fix (TAAF) program is being implemented, apply ESS just prior to the start of the TAAF program, while continuing to strive for an optimum screen.
- Document ESS requirements and appropriate details such as profiles, screening equipment and

fixtures as part of the product technical data package (TDP). The requirements shall be referenced on the appropriate part/assembly drawings or parts list. Include in the TDP the statement: "To the extent that the profiles are equipment and/or manufacturer unique, they may have to be modified due to changes in material or production processes."

- Finalize the ESS profile before the system enters into production. The following guidelines are provided to assist program managers in determining whether or not a reasonable screening profile has been developed. One or more of the following techniques may be required.
  - Verify that the more severe temperature screening profiles are used at the lower assembly levels (e.g., printed wiring assembly, module, subsystem, etc.). A good ESS program should drive out most faults at the lower levels where faults are more easily corrected and less costly to repair.
  - Verify that the proposed screening profiles meet or exceed the Tri-Service baseline presented in Tables 3-3 and 3-4. When the profiles do not meet or exceed the baseline, verify that rationale for this deviation is acceptable.
  - Verify that the proposed screening profile is not so severe that it is damaging to the item being stressed. By reviewing failure analyses a determination can be made whether or not a failed component has been overstressed. If the results of this review indicate that the item is being overstressed, the screening profile should be adjusted until failure analyses indicate no failures are due to overstressing. In some cases a minor design change, such as additional support for a resonant component, would be a more logical and cost effective solution.
  - Verification may be made that a screening profile is adequate by seeding known faults into an item and then determining if the proposed screening profile is adequate to precipitate them to hard failure.

The profiles should not change unless the manufacturing processes are changed, the system is redesigned, parts are changed, or a different type of screen is found to be more effective.

PRODUCTION AND DEPLOYMENT

- Establish or continue a closed-loop FRACAS to report and analyze faults that are precipitated out during screening.
- Establish procedures to correct/monitor any workmanship/parts problems identified during screening. Screens help to identify processes (both in-house and vendor processes) that are "out of control."
- Provide parts failure information to parts manufacturers and require continuous improvements to reduce these deficiencies.
- Establish procedures to track fielded systems and evaluate field failure information against the effectiveness of the current screens wherever possible.
- Establish criteria acceptable to the Government on when and under what conditions 100% screening should be reduced to sampling. See continuous sampling plans in MIL-STD-1235 (Reference B.1-12).

REPROCUREMENT AND DEPOT LEVEL OVERHAUL

- Derive the same benefits of ESS in reprocurement items and depot overhauled items as initial production environments. Though the frequency of failure may be lower for depot overhaul items (infant mortality/design updates are already in place through field use), poor workmanship and bad replacement parts are still a problem in the depot overhaul environment.

  Note: Numerous applications of ESS may be harmful to equipment. Depending on the particular equipment, the ESS program and the frequency of overhaul, some useful life of the equipment may be consumed.

- Require that all equipment that are reprocurements be screened if ESS was required on the original procurement contract. System level equipment should be screened at the originally developed screen or at a government approved equivalent screen. Where original screens were not developed

for replacement modules, a determination based on criticality and cost should be made to determine whether or not to develop an appropriate screen.

- Establish a FRACAS whenever there is a screening effort.

2.7 GUIDANCE SUMMARY

While individual program managers have great leeway on implementing ESS, the overall direction is clear. Top management's commitment and attention is the key element in a successful ESS program. The following summarizes the ESS guidance:

- Define contractual requirements.
- Identify a general approach to satisfy these requirements.
- Perform a cost analysis considering the following:
  - Assembly level at which to apply ESS
  - Level of automation versus manual labor
  - Specific rates of thermal change versus capital investment
  - Adequacy of available in-house random vibration equipment versus cost of off-site screening or the purchase of new equipment
  - Cost considerations of active power-on versus passive power-on screening
- Consider sampling for the ESS screen based on screening data collected, but only with customer concurrence.
- Coordinate the ESS program with other activities relating to quality and reliability.
- Ensure that a FRACAS has been implemented.

SECTION 3
ENGINEERING GUIDANCE

This section discusses the technical issues that arise when implementing an ESS program. These issues are related, and decisions concerning them should be made in an interactive manner.

ESS is a manufacturing process and should not be confused with a test. Ideally, a screening program should be designed for the system (equipment unique) to which it is to be applied. Such custom designing may require the expenditure of resources to perform additional analyses. Baseline screening parameters have been provided in this section and should serve as a starting point only for custom designing a profile unique to the particular item. The contractor should not implement screening at or below baseline screening parameters without prior Government approval.

3.1 TECHNICAL ISSUES

TYPES OF FLAWS TO BE PRECIPITATED

Based on the types of failures expected in the product, product responses to environmental stimuli and the sensitivity to these responses, product unique ESS profiles can be developed. Table 3-1 gives examples of typical defects that are sensitive to either thermal cycling, vibration or both. This table can be used as a guide in developing tailored ESS profiles. Care must be taken that in tailoring to one type of failure, other classes of failures are detected.

LEVELS OF ASSEMBLY AT WHICH ESS SHOULD BE PERFORMED

The term *piece part* as used herein is defined as a monolithic integrated circuit, resistor, switch, etc., which is the lowest level of assembly. The next level of assembly is a multi-part assembly that has a defined identity — e.g., one that is given a drawing number and, usually, a name. A typical item at this level is a *printed wiring assembly* (PWA) or an equivalent *shop replaceable unit* (SRU). The top level is a *system*, but one person's system is another's subsystem (engine, propulsion system, air vehicle, weapon system). In reality, there is always some aggregate that is the

TABLE 3-1. SCREENING ENVIRONMENTS VERSUS TYPICAL FAILURE MECHANICS

	SCREENING ENVIRONMENT		
	THERMAL CYCLING	**VIBRATION**	**THERMAL OR VIBRATION**
TYPE OF FAILURE	COMPONENT PARAMETER DRIFT PWA OPENS/SHORTS COMPONENT INCORRECTLY INSTALLED WRONG COMPONENT HERMETIC SEAL FAILURE CHEMICAL CONTAMINATION DEFECTIVE HARNESS TERMINATION IMPROPER CRIMP POOR BONDING HAIRLINE CRACKS IN PARTS OUT-OF-TOLERANCE PARTS	PARTICLE CONTAMINATION CHAFED, PINCHED WIRES DEFECTIVE CRYSTALS MIXED ASSEMBLIES ADJACENT BOARDS RUBBING TWO COMPONENTS SHORTING LOOSE WIRE POORLY BONDED COMPONENT INADEQUATELY SECURED PARTS MECHANICAL FLAWS IMPROPERLY SEATED CONNECTORS	DEFECTIVE SOLDER JOINTS LOOSE HARDWARE DEFECTIVE COMPONENTS FASTENERS BROKEN COMPONENT SURFACE MOUNT TECHNOLOGY FLAWS IMPROPERLY ETCHED PWAs

largest entity reasonably possible to subject to ESS. In any event, there usually are several levels of assembly at which ESS can be contemplated.

It is more cost effective to do ESS at the lowest level possible and at more than one level. The choices of how many levels and which levels will involve an engineering evaluation.

The costs associated with a failure usually appear in connection with a single part or interconnection and will increase dramatically with the level of assembly. Consider the following brief list, which will vary depending upon the manufacturer, complexity of the item and how much control the manufacturer has of his process:

- At higher levels
  - More assembly work has to be undone and redone when failures occur
  - More material may need to be scrapped
  - More impact on production flow and schedule usually occurs
- At lower levels
  - Corrective action is quicker
  - Repair cost is lower

The above factors tend to lead management to decide to perform ESS at lower levels of assembly. However, each step in assembly and integration provides additional opportunities for the introduction of flaws. Obviously, ESS at a particular level cannot uncover flaws that are not introduced until the next level. *Generally, this dilemma is usually controlled by performing ESS at each major functioning level in the manufacturing process consistent with an assessment of the potential defect population at each level of assembly.*

Resolution of these conflicting considerations usually involves screening at multiple (usually 2 or 3) levels of assembly. ESS at lower levels should focus on surfacing and correcting flaws in piece parts and PWA processing. Thus, most ESS failures at higher levels will reflect flaws introduced later in the manufacturing sequence that are usually correctable without tear-down to the PWA level. Table 3-2 provides a summary of the risks and results of doing ESS at various levels and functional conditions.

TYPES AND SEVERITIES OF STRESSES

A variety of environmental stresses have been candidates for use in ESS over the years. Of these, random vibration and thermal cycling currently are considered to be the most cost effective. Table 3-1 identifies some common types of failures and reflects whether random vibration or thermal cycling is the more likely stress to precipitate that particular failure. A failure may also be surfaced under one stress, but detected under the other. The references in Appendix B present other screening techniques which may be appropriate for some products.

Traditional ESS, consisting of temperature cycling and random vibration, may not be the most effective environment to use for certain hardware. For example, power cycling is effective in precipitating certain types of latent defects; pressure cycling may be desirable for sealed equipment; and acoustic noise may excite microelectronics structures better than structure-borne vibration. Ultimately, ESS environments must be chosen based on the types of flaws that are known or expected to exist.

In the past, fixed-frequency or swept-sine vibration were sometimes used. These practices were attributable in part to costs and physical limitations of available test equipment at the time. However, the major reason is believed to be the lack of recognition of the shortfalls of fixed frequency and swept-sine vibration in comparison with broadband random vibration.

Today, true random and quasi-random vibration are used almost exclusively for ESS. True random vibration, which is well known in the ESS community, applies all frequencies in a certain bandwidth (usually 20 to 2000 Hz) and is neither cyclic nor repetitive. Quasi-random vibration, on the other hand, is a relatively new technology using pneumatically driven vibrators which generate repetitive pulses. For screening applications, several (usually 4 to 6) of these vibrators are attached to a specially designed shaker table which is allowed to vibrate in multiple axes simultaneously. This complex motion (6 degrees of freedom vibration — 3 linear axes and 3 rotational axes) is very effective in finding all types of flaws.

It is not difficult to visualize that the complex interactions possible under random vibration can induce a wider variety of relative motions in an assembly. As indicated by Table 3-1, vibration is the area of

TABLE 3-2. RISKS AND RESULTS OF ESS AT VARIOUS LEVELS

ESS CONDITIONS/TRADEOFFS							RISKS/EFFECTS			
LEVEL OF ASSEMBLY	POWER APPLIED[1]		I/O[2]		MONITORED[3]		ESS COST	TECHNICAL		COMMENTS
	YES	NO	YES	NO	YES	NO		RISK	RESULTS	
TEMPERATURE CYCLING										
PWA		X		X		X	LOW	LOW	POOR	CONDUCT PRE & POST ESS FUNCTIONAL TEST SCREEN PRIOR TO CONFORMAL COATING.
	X			X		X	HIGH	LOWER	BETTER	
	X		X		X		HIGHEST	LOWEST	BEST	
UNIT/BOX	X		X		X		HIGHEST	LOWEST	BEST	IF CIRCUMSTANCES PERMIT ESS AT ONLY ONE LEVEL OF ASSEMBLY, IMPLEMENT AT UNIT LEVEL.
	X			X	X		LOWER	HIGHER	GOOD	
		X		X		X	LOWEST	HIGHEST	POOR	
SYSTEM	X		X		X		HIGHEST	SEE COMMENT		MOST EFFECTIVE ESS AT SYSTEM LEVEL IS SHORT DURATION RANDOM VIBRATION TO LOCATE INTERCONNECT DEFECTS RESULTING FROM SYSTEM INTEGRATION.
RANDOM VIBRATION										
PWA	X		X		X		HIGHEST	LOW	GOOD	RANDOM VIBRATION IS MOST EFFECTIVE AT PWA LEVEL IF: 1. SURFACE MOUNT TECHNOLOGY IS UTILIZED 2. PWA HAS LARGE COMPONENTS 3. PWA IS MULTILAYER 4. PWA CANNOT BE EFFECTIVELY SCREENED AT HIGHER ASSEMBLIES
	X			X	X		HIGH	HIGH	FAIR	
		X		X		X	LOW	HIGHEST	POOR	
UNIT/BOX	X		X		X		HIGHEST	LOW	BEST	RANDOM VIBRATION MOST EFFECTIVE AT THIS LEVEL OF ASSEMBLY. INTERMITTENT FLAWS MOST SUSCEPTIBLE TO POWER-ON WITH I/O ESS. POWER-ON WITHOUT I/O REASONABLY EFFECTIVE. DECISION REQUIRES COST BENEFIT TRADEOFF.
	X			X	X		LOW	HIGHER	GOOD	
		X		X		X	LOWEST	HIGHEST	POOR	
SYSTEM	X		X		X		LOW	LOW	GOOD	COST IS RELATIVELY LOW BECAUSE POWER AND I/O NORMALLY PRESENT DUE TO NEED FOR ACCEPTANCE TESTING.

NOTES:

1. POWER APPLIED — AT PWA LEVEL OF ASSEMBLY, POWER ON DURING ESS IS NOT ALWAYS COST EFFECTIVE — SEE TEXT
2. I/O — EQUIPMENT FULLY FUNCTIONAL, WITH NORMAL INPUTS AND OUTPUTS
3. MONITORED — MONITORING KEY POINTS DURING SCREEN TO ASSURE PROPER EQUIPMENT OPERATION

stressing that normally precipitates latent assembly flaws caused by the undesired relative motion of parts, wires, structural elements, etc., as well as mechanical flaws that lead to propagating cracks.

Burn-in has been defined many ways by different agencies and companies; however, for this document it is the exposure of powered equipment to either ambient or steady elevated temperature. This technique has been used in the past with some success and needs to be considered as a possible supplement to the ESS requirement. It is of particular value where components are of high power and where heat buildup occurs over a long period. Burn-in is not a substitute for ESS.

Effective screening usually requires large, rapid temperature changes and broadband random vibration. Such thermal cycling is used for the detection of assembly flaws that involve installation errors or inadequate chemical or mechanical isolation or bonding. Under rapid thermal cycling (e.g., in solder joints), differential thermal expansion takes place without sufficient time for stress relief, and this is a major mechanism for precipitating latent defects to detectable failures.

As indicated in Table 3-1, some types of flaws may be precipitated to failures by either thermal cycling or random vibration. However, it is important to note that thermal cycling and random vibration are synergistic. For example, thermal cycling following random vibration sometimes leads to detection of vibration induced failures that were not apparent immediately. There have been reported cases where a very small flaw did not propagate to the point of detectability during random vibration, but advanced to the point of detectability during subsequent thermal cycling.

The combined efforts (synergism) between vibration and thermal cycling suggests that concurrent application of the two stress types may be desirable. This combined environment is in fact sometimes used in ESS, but more often is avoided because it requires more elaborate facilities. Also, concurrent application of random vibration and thermal cycling can make it difficult to determine what caused a defect so that corrective action can be taken.

If random vibration and thermal cycling are to be conducted sequentially, random vibration would usually be done first. A more effective sequence would be five minutes of random vibration prior to thermal cycling, and another five minutes of random vibration following.

FAILURE DETECTION

Measurements During Thermal Cycling

Two approaches exist to monitoring equipment during thermal cycling. The first approach utilizes periodic measurement. In this approach, limited performance measurements are necessary prior to and at the end of ESS. These performance measurements may be made on the first and last cycle. Additional measurements may be taken at other cycles, if desired. Each measurement should be made at the hot and cold operating extremes.

The second approach calls for continuous monitoring of equipment operation during the "cold-to-hot" transition and the "hot" dwell portion of each cycle.

Measurements During Random Vibration

The strong argument for monitoring equipment during vibration screens is that the resulting movement of a marginal component may show up as an equipment failure only during the stress application. Otherwise, the incipient failure will escape detection, only to show up in an operational environment. Some of the initial work in random vibration screening indicated a 2:1 difference in the efficiency of the screen if the equipment were powered and monitored versus not powered. The technical risks and costs are summarized in Table 3-2 at each level of assembly for random vibration screening.

BASELINE ESS PROFILES

The baseline profiles (Tables 3-3 and 3-4) represent the combined agreement of the three Services on minimum levels to ensure effectiveness. They are derived from experimental and analytical stress screening studies plus surveys of screens used in industry. The random vibration baseline profile given in Table 3-3 shows the values for response levels, frequencies, axes, duration and monitoring. The thermal cycling baseline profile given in Table 3-4 shows a range of values for the temperature extremes, the temperature rate of change and the number of cycles.

These baseline profiles for random vibration and temperature cycling are *not* recommended stress levels, and should be used only as starting points to develop unique optimum profiles for a particular configuration. If the response levels in Tables 3-3 and 3-4 exceed the design capability of the unit and/or system, the contractor should submit appropriate rationale with supporting data to the Government for a waiver or deviation.

The most significant conclusion of ten years of random vibration screening is that the excitation must be tailored to the response experienced by the components of the unit under test. The selection of stress levels must be based on available data and structural design due to the potential for highly resonant members, as well as the existence of vibration sensitive electro-optical and electromechanical devices. *To avoid potential fatigue or peak level damage due to resonances, some level reduction of the input spectrum may be done at points of severe resonant frequencies which result in amplification of the applied stress level by a factor of 6 dB or more.* These resonances would be obtained from data accumulated during development tests, or by conducting a low-level sine sweep.

TABLE 3-3. BASELINE VIBRATION PROFILE

CHARACTERISTIC	LEVEL OF ASSEMBLY		
	PWA [1]	UNIT	SYSTEM
OVERALL RESPONSE LEVEL [2]	$6g_{RMS}$	$6g_{RMS}$	$6g_{RMS}$
FREQUENCY [3]	20 - 2000Hz	20 - 2000Hz	20 - 2000Hz
AXES [4] (SEQUENTIALLY OR SIMULTANEOUS)	3	3	3
DURATION			
– AXES SEQUENTIALLY	10 MINUTES/AXIS	10 MINUTES/AXIS	10 MINUTES/AXIS
– AXES SIMULTANEOUSLY	10 MINUTES	10 MINUTES	10 MINUTES
PRODUCT CONDITION	UNPOWERED (POWERED IF PURCHASED AS AN END ITEM DELIVERABLE OR AS A SPARE)	POWERED, MONITORED	POWERED, MONITORED

NOTES:

PURE RANDOM VIBRATION OR QUASI-RANDOM VIBRATION ARE CONSIDERED ACCEPTABLE FORMS OF VIBRATION FOR THE PURPOSE OF STRESS SCREENING. THE OBJECTIVE IS TO ACHIEVE A BROAD-BAND EXCITATION.

1. WHEN RANDOM VIBRATION IS APPLIED AT THE UNIT LEVEL, IT MAY NOT BE COST EFFECTIVE AT THE PWA LEVEL. HOWEVER, PWAs MANUFACTURED AS END ITEM DELIVERABLES OR SPARES MAY REQUIRE SCREENING USING RANDOM VIBRATION AS A STIMULUS. HOWEVER, AT THE SYSTEM LEVEL, WHEN A RESPONSE SURVEY INDICATES THAT THE MOST SENSITIVE PWA IS DRIVING THE PROFILE IN A MANNER THAT CAUSES SOME PWAs TO EXPERIENCE A RELATIVELY BENIGN SCREEN, THAT PWA SHOULD BE SCREENED INDIVIDUALLY. EACH PWA SCREENED SEPARATELY SHOULD HAVE ITS OWN PROFILE DETERMINED FROM A VIBRATION RESPONSE SURVEY.
2. THE PREFERRED POWER SPECTRAL DENSITY FOR $6g_{RMS}$ CONSISTS OF 0.04 g^2/Hz FROM 80 TO 350 Hz WITH A 3 dB/OCTAVE ROLLOFF FROM 80 TO 20 Hz AND A 3 dB/OCTAVE ROLLOFF FROM 350 TO 2000 Hz.
3. VIBRATION INPUT PROFILE FOR EACH SPECIFIC APPLICATION SHOULD BE DETERMINED BY VIBRATION RESPONSE SURVEYS WHICH IDENTIFY THE CORRELATION BETWEEN INPUT AND STRUCTURAL RESPONSES. HIGHER FREQUENCIES ARE USUALLY SIGNIFICANTLY ATTENUATED AT HIGHER LEVELS OF ASSEMBLY.
4. SINGLE AXIS OR TWO AXIS VIBRATION MAY BE ACCEPTABLE IF DATA SHOWS MINIMAL FLAW DETECTION IN THE OTHER AXES.

Notching (but not notching out) may be permitted with government approval, but should be the exception, not the general rule. Where warranted, temporary stiffening of the unit should also be considered to prevent overstressing during the stress screen. The design agency may find that the most economic approach is a minor design change to provide permanent stiffening. Whether temporary or permanent, the stiffening should be done in a manner which achieves the desired flat response throughout the unit being screened.

The temperature cycling screens also have to be tailored to each specific equipment and are equipment unique. Differences in components, materials and heat dissipation lead to variations in the thermal stresses throughout the item.

OPTIMIZING/TAILORING OF ESS

The Environmental Stress Screening Plan should allow the manufacturer to optimize a particular profile as needed, with government approval. The flexibility to change the screens as new parts, vendors, assemblies and new or alternate materials arise is also essential for a good ESS program.

For any given part or production process, there exists a level of ESS stress that is optimal, i.e., maximizes the likelihood of flaw detection without significant degradation of the unit undergoing ESS. Determining this optimal level is normally referred to as the optimization of a profile for an individual piece of equipment.

TABLE 3-4. BASELINE THERMAL CYCLE PROFILE

CHARACTERISTIC [1]	LEVEL OF ASSEMBLY		
	PWA [2]	UNIT [3]	SYSTEM
TEMPERATURE RANGE OF PRODUCT	-50°C TO +75°C	-40°C TO +70°C	-40°C TO +60°C
TEMPERATURE RATE OF CHANGE OF PRODUCT [4]	15°C/MINUTE TO 20°C/MINUTE	10°C/MINUTE TO 20°C/MINUTE	10°C/MINUTE TO 15°C/MINUTE
STABILIZATION CRITERION	STABILIZATION HAS OCCURRED WHEN THE TEMPERATURE OF THE SLOWEST-RESPONDING ELEMENT IN THE PRODUCT BEING SCREENED IS WITHIN 15% OF THE SPECIFIED HIGH AND LOW TEMPERATURE EXTREMES. LARGE MAGNETIC PARTS SHOULD BE AVOIDED WHEN DETERMINING THAT STABILIZATION HAS OCCURRED. [4]		
SOAK TIME OF PRODUCT AT TEMPERATURE EXTREMES AFTER STABILIZATION			
- IF UNMONITORED	5 MINUTES	5 MINUTES	5 MINUTES
- IF MONITORED	LONG ENOUGH TO PERFORM FUNCTIONAL TESTING		
NUMBER OF CYCLES	20 TO 40	12 TO 20	12 TO 20
PRODUCT CONDITION [5]	UNPOWERED/POWERED	POWERED, MONITORED	POWERED, MONITORED

NOTES

1. ALL TEMPERATURE PARAMETERS PERTAIN TO THE TEMPERATURE OF THE *UNIT BEING SCREENED* AND NOT THE *CHAMBER AIR TEMPERATURE*. THE TEMPERATURE PARAMETERS OF THE UNIT BEING SCREENED ARE USUALLY DETERMINED BY THERMOCOUPLES PLACED AT VARIOUS POINTS ON THE UNIT BEING SCREENED.
2. PWA GUIDELINES APPLY TO INDIVIDUAL PWAs AND TO MODULES, SUCH AS FLOW-THROUGH ELECTRONIC MODULES CONSISTING OF ONE OR TWO PWAs BONDED TO A HEAT EXCHANGER.
3. UNIT GUIDELINES APPLY TO ELECTRONIC BOXES AND TO COMPLEX MODULES CONSISTING OF MORE THAN ONE SMALLER ELECTRONIC MODULE.
4. IT IS UP TO THE DESIGNER OF THE SCREENING PROFILE TO DECIDE WHICH ELEMENTS OF THE HARDWARE (PARTS, SOLDER JOINTS, PWAs, CONNECTORS, ETC.) MUST BE SUBJECTED TO THE EXTREME TEMPERATURES IN THE THERMAL CYCLE. THE TEMPERATURE HISTORIES OF THE VARIOUS ELEMENTS IN THE HARDWARE BEING SCREENED ARE DETERMINED BY MEANS OF A THERMAL SURVEY.
5. POWER IS APPLIED DURING THE LOW TO HIGH TEMPERATURE EXCURSION AND REMAINS ON UNTIL THE TEMPERATURE HAS STABILIZED AT THE HIGH TEMPERATURE. POWER IS TURNED OFF ON THE HIGH TO LOW TEMPERATURE EXCURSION UNTIL STABILIZATION AT THE LOW TEMPERATURE. POWER IS ALSO TURNED ON AND OFF A MINIMUM OF THREE TIMES AT TEMPERATURE EXTREMES ON EACH CYCLE.

ESS tailoring (the modification of ESS parameters to fit specific hardware), if not planned and done properly, could be a major consumer of resources. Experience with similar hardware can be helpful in setting initial tailoring levels leading to a rough approximation of optimal parameters. However, a true optimization is likely to require an extensive, carefully planned effort.

Recommended tailoring techniques are given in Sections 4 and 5 for vibration screens and thermal cycling screens, respectively. These are not the only techniques available but are recognized throughout the industry as viable approaches for developing an acceptable profile. The selection and use of one or more of these techniques is usually predicated on such things as availability of screening equipment or cost of procurement, architecture of equipment to be screened and type of manufacturing defects expected, and maturity of design and manufacturing processes. *Trade-offs are needed because the payoff between "reasonably good" and "optimal" ESS parameters may not be commensurate with the costs of finding the optimal profile.*

Some specific engineering considerations in determining optimal ESS stress levels and making a sound engineering decision that tends to be on the conservative side (i.e., no overstressing) are as follows:

- Differences in physical characteristics such as thermal inertia, thermal conductivity, mechanical coupling, and mechanical resonant frequencies assure that differently configured assemblies will respond differently to identical thermal and vibrational inputs.
- Stress profiles should be defined in terms of responses rather than input. A uniform level of stress may not be achieved throughout the unit, because all units are not generally internally homogeneous. The response can be specified and measured at only a few points, so it will still differ locally within differently configured assemblies.

RELATIONSHIPS OF ESS TO OTHER ACTIVITIES IN PRODUCT DEVELOPMENT AND PRODUCTION

Since the primary purpose of ESS is to precipitate latent problems associated with the manufacturing processes, its effective use is predicated on good design with quality parts. Historically, ESS results show that failures due to workmanship are approximately two thirds of the total with the other third due to bad parts and poor design.

The ESS effort is expensive initially, particularly considering the associated costs of the capital investment. Additional recurring cost factors that will add to the overall cost include the utilities, failure analysis and corrective actions that go along with the associated FRACAS program and all the labor necessary to control the ESS program.

The ESS effort will be much more cost effective if it is not loaded down with failures due to an immature design and inferior parts. On the other hand, ESS is a major cost avoidance factor in manufacturing because the production process can be optimized, resulting in:

- Less teardown
- Less troubleshooting time
- Less failure reporting and corrective action
- Less repair time
- Less inspection time
- Less reassembly time
- Improved production personnel efficiency and proficiency
- More efficient utilization of production facilities

Parts Rescreening and Quality

Poor quality piece parts play havoc with printed wiring assembly (PWA) yields, with a resultant increase in assembly rework, cost and scrappage. Current guidelines being implemented by some Services call for 100% rescreening of microcircuits and semiconductors by Original Equipment Manufacturers (OEM) at receiving inspection. This is normally continued until a quality level of less than 100 defective parts per 1,000,000 parts shipped can be demonstrated. The emphasis is on vendor process control to improve quality of parts to an acceptable level rather than OEM rescreening. For information on parts rescreening and quality, see References B.2-4 and B.1-19.

Test, Analyze and Fix Programs

TAAF reliability growth testing programs are used extensively by the Services to identify and correct design deficiencies on new systems while still in the engineering & manufacturing development phase. As mentioned in Reference B.1-20, ESS should precede formal TAAF testing. This helps to minimize the occurrence of failures unrelated to design inadequacies. Unrelated failures tend to retard the TAAF process, lengthen its duration, and increase its total cost.

Reliability Demonstration and Production Reliability Acceptance Testing

All reliability predictions, demonstrations or tests are related to the system design and quality of parts used and do not consider workmanship or process deficiencies. Therefore, ESS is a necessary prerequisite for success in any reliability quantification based on failures and operating time. The failures that occur during ESS are not counted in subsequent reliability demonstrations but are input to a FRACAS program to prevent reoccurrence. See References B.1-9 and B.1-10.

Failure Reporting and Corrective Action System

One of the best practices in successful system development efforts is the proper implementation of a FRACAS. As defined in MIL-STD-1629, FRACAS is a "closed-loop system for initiating reports, analyzing failures, and feeding back corrective actions into the

design, manufacturing and test processes." Thus, ESS is an essential tie to the design and manufacturing processes during development and to statistical process control (SPC) of the manufacturing processes during production and depot repair.

SAMPLING VS 100% SCREENING

When an item has been in production for some time, manufacturing processes and purchased parts may have reached a steady state and be well controlled. Under these conditions, ESS will no longer be precipitating a significant number of failures. At this point, it can be argued that ESS is no longer productive and that resources could be conserved by discontinuing ESS. If it can be demonstrated that the decline in ESS failures is indeed due to improvements, and not to manufacturing changes that make the ESS conditions ineffective, suspension of 100 percent ESS may be considered. However, monitoring should be instituted to make sure that the improvements remain effective. The best way to accomplish this is to develop a sampling plan, with reversion to 100 percent ESS on evidence of loss of process control. One hundred percent ESS also should resume when processes, parts or sources are changed and after production breaks or new product introduction.

In most military contracts the production quantities are not sufficient to justify the effort necessary to go from 100% screening to a sampling procedure. See Reference B.1-12.

EQUIPMENT CONFIGURATION

If there are many small and different modules in the equipment, the cost of vibration fixtures for these modules may be prohibitive, especially if each is powered and monitored. A compromise, in this case, may be to do power-off thermal cycling only at the module level and do both thermal cycling and random vibration at the next higher level.

Conversely, if some equipments or cabinets are odd shaped or have heavy cantilevered components, for example, then it may be more cost effective to do only thermal cycling at this level and do both stress screens at a lower level of assembly. It is essential that these analyses result in a cost effective program to precipitate manufacturing defects.

MOUNTING SCHEMES

Even with relatively simple configurations and small module sizes, poorly designed mounting fixtures can severely distort the applied vibration spectrum and even cause unwanted failures due to structural resonances. Each vibration screen setup should ensure that the stress excitation is evenly applied to the product throughout the spectrum. Enough problems are encountered within the product without confounding the issue with resonances in the fixture. For example, fixture resonances and cost were countered in one program by suspending the product on "bungee" cords and using tri-axial excitation applied at the corner of the product.

Many temporary schemes can be used to damp excessive resonances within the product. These schemes include clamping, strapping or supporting the resonating area only for the duration of the vibration screen. Usually the amount of damping can be adjusted to obtain the desired responses.

PERFORMANCE MONITORING AND POWERED VERSUS UNPOWERED CONSIDERATIONS

In developing a screening program, an important consideration is whether the product should be powered or unpowered, monitored or unmonitored. Unless they are the end items, PWAs are usually unpowered because they aren't used as stand-alone items in the operational environment. In addition, appropriate screen equipment is usually not available to functionally monitor PWAs during the screening process. On the other hand, units and systems should be powered and monitored because they usually function as stand-alone items and appropriate test equipment is usually available to functionally monitor them.

During Thermal Screening

During thermal stress screening, whether performance monitoring should be required and/or when power should be applied are primarily determined by two factors:

- Without performance monitoring, intermittent failures may go undetected (this is an argument for performance monitoring with power applied).

- With power applied, the parts may not be able to be cycled over a large temperature range without overstressing some parts (this is an argument for unpowered equipment).

The availability of electrical test equipment is traditionally limited, and conflicts are generated between screening and bench test operations. In addition, schedules may be affected by the need to move and set up test equipment at each different location. If all of the failures that occurred were "hard failures" (i.e., failures that stay failed once they occur), performance monitoring might not be necessary. Unfortunately, many failures that occur in electronic hardware are intermittent failures and only occur while thermal stress is being applied.

Performance monitoring should be done at the lowest temperature limit and at the upper temperature limit of each thermal cycle. Monitoring at these temperature limits will detect intermittent defects that would not show up at room temperature. Power need not be applied during the entire thermal screen. Rather, it can be turned off during the cooling portion of the thermal cycle until temperature has stabilized at the low temperature. It is desirable to monitor performance while power is applied during the cold to hot ramp. The degree of monitoring needs careful study regarding cost effectiveness. Any attempt to monitor intermittent shutdowns for as short a period as 2 to 3 milliseconds may be very expensive.

During Random Vibration

Industry has developed the following information about power on/power off random vibration screening:

- *POWER OFF* is of some value. When power is not applied, approximately 50% of the defects are not precipitated to failure and all of the intermittent failures are not identified.

- *POWER ON, OUTPUTS INACTIVE* is of greater value. When power is on, but the hardware is not operating, about 70% - 80% of the defects are stimulated to failure.

- *POWER ON, OUTPUTS FULLY ON* is of most value in that all latent and intermittent defects are stimulated if there is an effectively designed random vibration screen. However, *all* random vibration defects won't be precipitated since the random vibration screen is of limited duration.

CHAMBER AIR FLOW CHARACTERISTICS

When any item is subjected to thermal cycling, the temperature of the item lags that of the chamber air because of thermal inertia and imperfect heat transfer. The thermal lag, i.e., the difference between the chamber air and hardware temperatures, increases with increasing equipment thermal inertia and with decreasing air speed. The thermal lag is greatest for heavy assemblies and for low speed air cycled at high rates of temperature change.

If the chamber air temperature rate of change is too high, the dwell time too short, and/or the chamber air too slow, the part temperatures will not attain the chamber air temperature extremes, resulting in a less effective screen.

In thermal stress screening, the rate of change of temperature is as important as the temperature extremes. The faster the rate of change, the more effective the temperature stress screen. But it is the individual components that must experience a particular rate of change of temperature and temperature extremes. To attain the appropriate temperature rate of change and temperature extremes of the item being screened, there are several things that the screen designer may be able to do:

- Allow the ESS chamber to "overshoot" the temperature parameters. Overshooting is a method of achieving an increased temperature rate of change and higher/lower temperature extremes when the chamber air temperature exceeds the upper and lower screening temperature limits for a controlled period of time. Controlled overshooting is permissible and encouraged as an excellent method of achieving higher temperature rates of change, thereby increasing screen effectiveness. To avoid overstress at temperature extremes, the temperature of (or immediately adjacent to) the part with the smallest thermal mass should be monitored with thermocouples, if practical.

- If practical, remove the protective covers of the equipment, thus allowing the chamber air flow to more easily reach the individual components.

- Install an air circulating system. In many units, the electronic parts are densely packaged, thus increasing the thermal mass of the unit. As the thermal mass increases, the air flow becomes more restricted. To compensate for this, an air circulating system (e.g., a fan) can be installed to direct the air to the areas of the unit with the highest thermal mass, thus causing the components to experience a much greater temperature rate of change.
- PWAs and subassemblies which are not conformally coated may suffer damage or intermittent operation due to condensation in the chamber. Consideration should be given to using an air drying system or some other means of minimizing this condensation.

REPEATED SCREENING

Repeated application of screens after correction of ESS flaws can very easily begin to use up significant useful life and to initiate rather than precipitate flaws. To avoid such counter-productive screening, the following guidelines are recommended:

- After repair of failure during first operating vibration screen, complete remaining duration of screen, or five minutes, whichever is greater.
- After repair of failure during first non-operating vibration screen, repeat screen as a confidence check at full level and 50% duration.
- After subsequent repairs and/or modifications, repeat original screen at -3 dB level (70% g_{RMS}) for 50% duration.
- Do not exceed five vibration exposures.
- If failure is detected and repaired during the initial thermal cycling screen, the balance of the cycles scheduled, or a minimum of three, should be run.
- After subsequent repairs and/or modifications, run one complete thermal cycling screen.

The guidelines above should be used in conjunction with alerting Government and contractor program managers and an assessment of the appropriate amount of rescreening which takes into account the nature of the repair/modification, the amount of teardown, rework and reassembly involved, and the chance for introducing workmanship flaws. Such assessments are appropriately made through Corrective Action Board/Failure Review Board actions.

3.2 GUIDANCE SUMMARY

The following summarizes the ESS engineering guidance provided in this Section:

- Identify the nature of anticipated defects for unit design and manufacturing processes.
- Select appropriate levels of assembly, e.g., printed wiring assembly, assembly, system, etc., at which ESS should be performed.
  - Review product design.
  - Evaluate repair cost at various levels against fixture and ESS costs, including teardown, repair, checkout, reassembly and the potential of introducing new defects.
- Develop and finalize the ESS profile:
  - Review available in-house and industry-wide data relative to the design of screening profiles for comparable equipment.
  - Review product design information to identify any thermal characteristics of mechanical resonances/ weakness which could impact detail of screening profiles.
  - Tailor and finalize the temperature cycling screen, at each level of assembly selected, for temperature limits, product rate of temperature change, number of temperature cycles, and whether monitored during screen.
  - Tailor and finalize the random vibration screen, at each level of assembly selected, for spectrum, g_{RMS} level, number of axes, true random or quasi-random, and whether the product is monitored during screen.
  - Optimize or modify the ESS profiles based on results from the screens and operational use.
- Assess the timeliness and comprehensiveness of the FRACAS and assure that the corrective action process for any inadequate manufacturing processes has been extended back to the OEM.
- Finalize the procedures governing the reapplication of ESS after correction of ESS related flaws.

SECTION 4

VIBRATION SCREEN DEVELOPMENT

There are several viable methods for developing a starting profile for vibration stress screening. *Starting* emphasizes that developing a screen is a dynamic process. The effectiveness of any screen should be evaluated by engineering analysis of the equipment and the expected flaws, using factory and field failure data, and the failure history of the equipment during and subsequent to the screen, adjusting the screen parameters as the screen matures.

Four methods are described herein in order of descending analytical complexity. Selection depends on such factors as: 1) hardware availability, 2) number and production rate of items to be screened, 3) availability of vibration equipment (shakers, data acquisition analysis, etc.), and 4) availability of experienced dynamic test or screening personnel. Table 4-1 gives some general considerations for selection of an appropriate method.

The baseline vibration profile in Table 3-3 recommends 3 axes vibration. However, screens developed using either Method A, B or C should be done in the critical axis (usually perpendicular to the plane of the printed wiring assemblies) first, with similar screens developed for the second and third axes. This procedure may eliminate vibration in the second or third axis as being ineffective in screening out defects. Where strong coupling exists between axes, all but the critical axis may be eliminated with Government approval as not cost effective in screening out defects.

4.1 METHOD A - VIBRATION SURVEY

This is the preferred method and has been used extensively. Two techniques are available: (1) a *general* technique based on recording and analyzing the data obtained to develop the spectral responses through-

TABLE 4-1. VIBRATION SCREEN DEVELOPMENT CONSIDERATIONS

METHOD	PRO	CON
A. VIBRATION SURVEY	TWO TECHNIQUES TO DETERMINE SPECTRAL RESPONSES FOR TAILORING	GENERAL SURVEY TECHNIQUE REQUIRES SPECTRAL ANALYSIS EQUIPMENT
B. STEP-STRESS TESTS	STRAIGHTFORWARD EMPIRICAL METHOD IF PERFORMED BY EXPERIENCED ENGINEERS MAY PROVIDE EQUIPMENT WITH INCREASED DURABILITY DEFINES ITEM DESIGN LIMITS IDEAL FOR EXISTING AND DEVELOPING TECHNOLOGY	SOME RISK OF OVERSTRESS IF DESIGN LIMITATION IS UNKNOWN EQUIPMENT MAY BE STRESSED TO DESTRUCTION SUFFICIENT EXPENDABLE ASSETS MAY NOT BE AVAILABLE DURING EARLY PRODUCT DEVELOPMENT PHASE
C. FAULT REPLICATION TESTS	GOOD SUPPLEMENT TO METHOD B	LACK OF HARDWARE WITH REPEATABLE FAILURE MODES DIFFICULTY IN "SEEDING" HARDWARE REALISTICALLY
D. HERITAGE SCREEN	MINIMUM DEVELOPMENT RESOURCES REQUIRED	TRANSPARENT DISSIMILARITIES MAY YIELD INADEQUATE OR DAMAGING SCREEN MINOR DESIGN CHANGES MAY INVALIDATE PREVIOUS ESS

out the unit being screened; and (2) a *simplified* technique wherein overall g_{RMS} level readings are obtained at the different sites to determine if some components are either overstressed or understressed.

GENERAL TECHNIQUE

The development of a random vibration stress screen is predicated on tailoring the input to achieve an acceptable response throughout the unit being screened. A vibration survey is the most logical and straightforward way to determine these responses. The spectral responses from selected accelerometer sites identify the frequencies where high responses or damping occur. The input vibration level at appropriate frequencies can then be tailored to eliminate undesired high or low responses.

CONFIGURATION

The vibration survey configuration should replicate the configuration for the proposed screen.

Item

The item must be representative of the product to be screened. It should be possible to mount accelerometers internally within the item. It should be permissible to accumulate vibration time on the item.

Level

The vibration survey should be conducted at an input random vibration level of 2-3g_{RMS}, which is 6 to 10 dB below the baseline screening level of Table 3-3. A low level sine vibration sweep can also be used to obtain a very good picture of resonance responses across the desired spectrum.

Strategy

The survey should be performed for each input axis or combination of input axes specified for the screen. For instance, a screen performed by the sequential excitation of three orthogonal axes requires three surveys. A screen performed as the combination of a dual axes excitation and a single axis excitation requires two surveys. A triaxial input screen requires one survey.

The controller, control strategy, and the number and location of control accelerometers should be the same as for the proposed screen.

Excitation System

The excitation system used for the survey should be the same as for the screen.

Fixturing

The fixture, slip-plate, and head expander used for the survey should be the same as for the screen. It is good practice to perform a vibration survey on the mounting fixture only prior to the item survey.

MEASUREMENT PHILOSOPHY

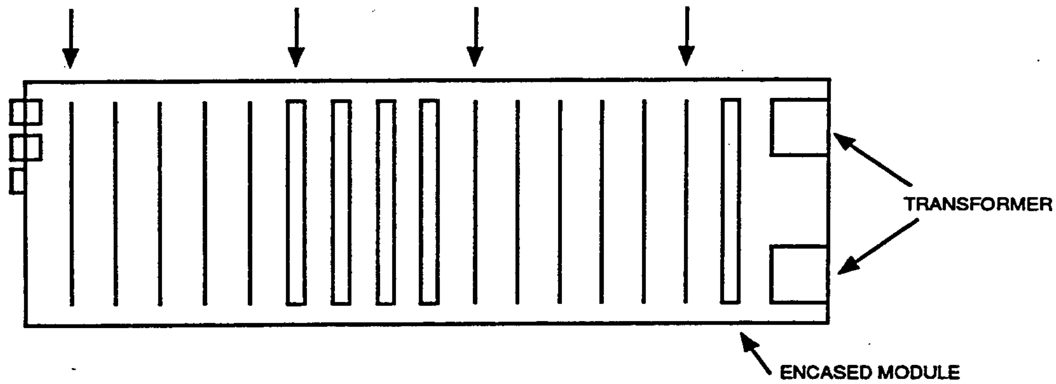
Selection of Measurement Locations

In an exhaustive survey, vibration response would be measured at each component, wire connection, mounting screw, etc., within the item to be screened. This clearly is neither feasible nor desirable. What is desirable is to measure vibration responses at locations throughout the item that are representative of responses at a majority of the potential failure locations. Approximately 20 locations should suffice for mapping most items.

An example of an item is shown schematically in Figure 4-1 to illustrate the selection of response locations. The item is an electronics card box with cable connectors and a time meter mounted on the front panel, and transformers mounted on the rear panel. There are 11 standard cards spread throughout the box: four heavier, stiffer cards are located in the center and an encased, thick module is located at the rear. The cards and module have connectors on the bottom which mate with the motherboard at the bottom of the box.

The three measurement locations on the cards are depicted in Figure 4-2. The locations indicated by "X" are suggested for a rectangular PWA with components mounted uniformly over the surface, supported along the short edges and a connector on the bottom. If the top of the PWA is supported by compression of a rubber gasket on the lid, the locations depicted by "O" would perhaps be a better choice. A square PWA

FIGURE 4-1. EXAMPLE OF A SCREENABLE ITEM SHOWING POSSIBLE MEASUREMENT LOCATIONS



• THREE LOCATIONS ON EACH OF THE FOUR CARDS INDICATED BY ARROWS.	12
• THREE LOCATIONS WITHIN THE ENCASED MODULE ON THE COMPONENT MOUNTING SURFACES.	3
• ONE LOCATION ON FRONT PANEL NEAR CONNECTORS AND TIME METER.	1
• TWO LOCATIONS ON MOTHERBOARD	2
• TWO LOCATIONS ON REAR PANEL AT DIAGONALLY OPPOSITE CORNERS OF ONE OF THE TRANSFORMERS.	2
TOTAL	20

equally supported on each edge could be sufficiently mapped with two locations: one in the center and the other at the middle of one edge. Obviously there are many location choices within this example, and within other items that differ significantly from the example. This illustrates mapping of the entire volume and indicates that engineering judgment must be exercised in the selection of measurement locations.

Accelerometers

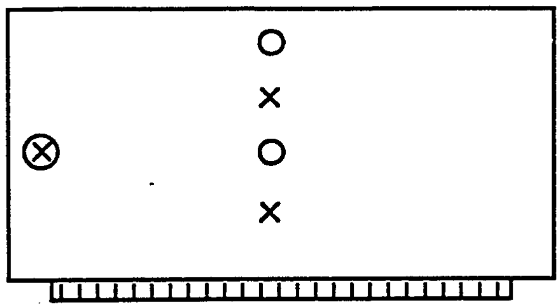
- Physical Characteristics

  Accelerometers should be small enough that they can be mounted in the chosen location and light enough that they do not alter the dynamic characteristics of the item. In most surveys a mix of accelerometer types can be used. In the example shown in Figure 4-1, relatively large, heavy accelerometers could be used to measure the acceleration input to the connectors/time meter on the front panel. Similar accelerometers could be used on the rear panel at diagonally opposite corners of the transformer. Medium size and weight accelerometers could probably be used on the motherboard and stiffer PWAs. The standard PWAs normally require the smallest, lightest accelerometers available so as to not alter the dynamic characteristics and to fit available mounting space.

- Triaxial Measurement

  The acceleration in three orthogonal directions must be known for each chosen measurement location. This does not mandate a triaxial measurement at each location. A measurement from another location may be substituted for one of the triaxial measurements if the response is judged to be the same over the frequency range of interest. As an example, triaxial response at the three measurement locations depicted on the card in Figure 4-2 can be acquired by using five accelerometers. A single accelerometer is needed at each of the three measurement locations with the sensitive axis oriented perpendicular to the plane of the PWA. The in-plane response should be the same for all locations on the PWA and can be

FIGURE 4-2. RESPONSE MEASUREMENT LOCATIONS ON RECTANGULAR PWA WITH BASE CONNECTOR



acquired by placing the two accelerometers wherever there is adequate space. Triaxial measurements will be required only if the contractor has equipment capable of triaxial excitation.

- Installation

  Accelerometers should measure the input to components or parts, not the response of a particular component or part. In the example shown in Figure 4-1, this means placing accelerometers on the PWAs, not the components, and on the front and rear panel, not the parts mounted to the panels.

Data Acquisition

It is assumed that the control and response acceleration data will be recorded and played back to a spectrum analyzer for data analysis. Alternatively, if the spectrum analyzer has enough data channels, the data analysis could be performed "on-line," obviating the need to record and later play back data for spectral analysis. If a recorder is not readily available, or if the number of available accelerometer channels is limited, the survey can be accomplished in segments by analyzing the response of each available accelerometer and moving the accelerometer to another location or direction. In most cases this can be done quite efficiently with minimum impact to the overall survey.

Data Acquisition Equipment

The data acquisition system, i.e., accelerometers, signal conditioners, and recorder system, should have sufficient dynamic range to observe and record the response accelerations. The system should be compatible within itself and with the data analysis equipment.

Recorder Setup

The recorder speed should be sufficient to obtain the desired frequency response for the acquired data.

For the first data acquisition run in each survey, all control accelerometers should be recorded along with the response accelerometers. For all remaining data acquisition runs in each survey, one control accelerometer should be recorded with the response accelerometers. The control accelerometer should remain the same for all remaining runs to validate repeatability in case of questionable response data.

Documentation

Documentation for the data acquisition should include the following information:

- Screen identification
  - program name

- item name screening station
- recorder
- engineer
- date
- excitation system

• Channel information
- accelerometer identification
- accelerometer serial number
- accelerometer sensitivity
- charge amplifier gain
- charge amplifier serial number

• Run information
- run identification
- frequency range and level of excitation

Calibration

The full scale *g* level of each channel should be estimated for each survey location prior to performing the data recording. This calculation or estimate will significantly reduce the instrumentation error caused by noise threshold or saturation.

A calibration signal, preferably a sine wave representing the full scale *g* level of the instrumentation, should be placed on each tape data channel. The run identification should note the voltage level, equivalent *g* level, and frequency of the calibration signal. The calibration should be recorded for at least two minutes after any changes in the patching of charge amplifiers to the recorder, and at any time that there is a question as to whether the input gains have been adjusted since the previous run.

It is also desirable for a broadband, approximately white noise, random signal to be recorded. The frequency range of the noise signal should extend over the frequency range of the excitation and its voltage amplitude should be within the dynamic range of the recorder. This signal, coming from one source, should be recorded simultaneously on all active data channels at the beginning of each run for a period of one minute. Record the true RMS voltage level of this signal during playback. This signal permits the frequency response of each channel and the transfer function between any two channels to be measured. Any discrepancies that are found can be compensated for during analysis.

Data Recording and Review

The minimum duration for recording of data should be the time necessary to calculate acceleration spectral density (ASD) functions over the desired frequency range, using 50 averages. This minimum time will vary, depending on the analysis block size and bandwidth, the number of channels processed simultaneously, and the analyzer computational speed. The entire run should be recorded if the screen is a nonstationary process. The data should be reviewed after the run to confirm that the amplitudes are appropriate, that the waveforms appear reasonable, and that the data segment is properly identified. The gain setting of each channel should also be verified.

DATA PROCESSING

The end result of the vibration survey should be a collection of ASD functions on a mass storage device available for "massaging." ASD functions should be calculated for all control and response accelerometers.

Data Analysis Equipment

It is recommended that the data processing be performed by playing back the recorded data to a digital Fourier spectrum analyzer. The analyzer should have the capability to calculate ASD functions, label the functions, and store the functions and labels on a mass storage device such as disk or tape. Additionally, the analyzer should be able to retrieve a stored ASD, integrate the function over selected frequency ranges to obtain g_{RMS} values, and print the g_{RMS} values.

Data Analysis Parameters

ASD functions should be calculated with 50 averages. An analysis bandwidth of approximately 5 Hz should be used for ASD calculation over the frequency range of 20 Hz to 2000 Hz. Alternatively, a constant percentage bandwidth analyzer may be used if the bandwidth does not exceed 1/6th octave.

TABLE 4-2. DATA ANALYSIS LOG PARAMETERS

• PROGRAM NAME	• NUMBER OF AVERAGES
• UNIT NAME	• CHARGE AMPLIFIER GAIN
• DATE	• RECORDER CHANNEL
• RUN IDENTIFICATION	• MASS STORAGE DEVICE & LOCATION NUMBER
• BLOCK SIZE	• MEASUREMENT IDENTIFICATION
• FREQUENCY RESOLUTION	
• FREQUENCY RANGE	

Documentation

Each ASD function should be stored with a unique identifier. A data analysis log should record the run information and analysis parameters shown in Table 4-2.

PROCEDURE

The following vibration survey procedure assumes that data is recorded on analog tape and played back to a spectrum analyzer for ASD calculation. The procedure can be modified for use with an on-line spectral analysis system.

The procedure also assumes that the excitation system is an electrodynamic shaker. For other types of excitation systems, not all steps will be relevant.

1. Record the calibration signal on all data channels of the tape recorder.
2. Record the white noise on all data channels of the tape recorder.
3. Attach any accelerometers and cables that require special treatment (disassembly of unit, cleanroom facilities, obstructions when installed in the fixture, etc.) to the unit.
4. Create or retrieve input specification on the controller.
5. Mount fixture to shaker table. Torque to specified values.
6. Mount control accelerometer(s) to fixture and patch to controller and data acquisition system.
7. Perform vibration dry run(s) to fixture and patch to the controller and data acquisition system.
8. Mount unit in fixture. Torque to specified values.
9. Attach remainder of response accelerometers and cables for this data run (attach accelerometers and cables for all runs if available).
10. Patch response accelerometers for this run to data acquisitions system.
11. Tap check all accelerometers to verify that they are properly patched to the input of the tape recorder and that all instrumentation functions properly.
12. Install all lids, covers, and unit cabling that will be on during screening.
13. Perform vibration run, recording all data.
14. Verify that the recorded data is valid before proceeding to the next run.
15. Repeat steps 9 through 14 for remaining groups of response accelerometers.
16. Repeat steps 4 through 15 for additional surveys, if applicable.
17. Analyze recorded data to obtain ASD functions. Label and store functions on the mass storage device for later retrieval and "massaging."

Compare vibration survey response spectra against allowable stress limit criteria applicable to the assembly under evaluation. Subsequent engineering analyses may result in appropriate hardware modifications to

remove vibration screening concerns. In addition, tailoring of the input spectrum is a viable alternative for reducing response maxima to within allowable stress limits. However, because extensive tailoring can adversely affect the ability to stimulate defects throughout the entire assembly, it should be viewed as the exception, not the general rule. Where warranted, temporary stiffening or damping of the assembly should be considered to eliminate the need for tailoring.

SIMPLIFIED TECHNIQUE

The simplified vibration survey technique is a modification of the general technique. The general technique is based on recording and analyzing the data obtained to develop the spectral responses throughout the unit being screened, but there are many situations where neither the equipment nor the associated trained personnel are available to do this. For these situations the general technique can be modified so that only overall g_{RMS} level readings are obtained at the different accelerometer sites throughout the unit being screened. Comparing these overall g_{RMS} values will determine if some components are either overstressed or understressed due to structural resonances or damping, respectively. There is some risk that responses peculiar to random vibration may be missed.

If the mean RMS response derived from multiple locations on an assembly are within +6, -3 dB of the input excitation level, no tailoring may be required. Since overall level is only a crude indication of spectral response, if the responses for individual locations differ appreciably from the mean RMS level, a vibration response survey should be conducted at an excitation level of 6 to 10 dB below the baseline screening level of Table 3-3 (2 to $3g_{RMS}$).

4.2 METHOD B - STEP-STRESS TESTS

Step-stress testing is an empirical procedure that can be used when resources for elaborate surveys, recording, analysis and technical support are limited. Due to the associated inaccuracies and risks, however, its use must be approved by the government.

The step-stress approach determines the "tolerance limit" or design capability of the hardware for the screen. By knowing this limit, a safe screening level can be determined and changed as required to obtain satisfactory screening results. The overall input level is tailored to the product.

As in Method A, the vibration survey test configuration should replicate the configuration for the proposed screen. The test item must be representative of hardware to be screened. It should be permissible to accumulate vibration time on the test hardware. The fixture, slip-plate, and head expander used for the survey should be the same as for the screen.

PROCEDURE

Step-Stress tests proceed as follows:

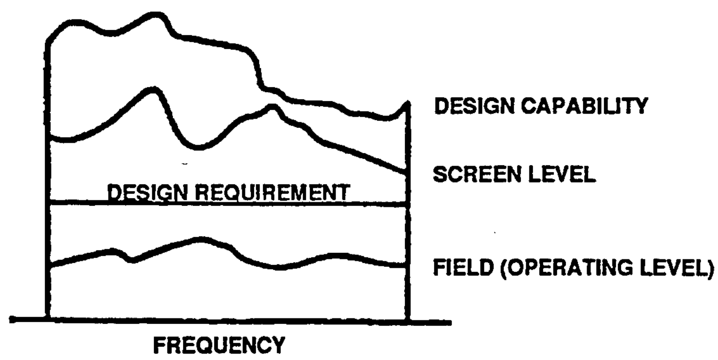
1. Use a broadband spectrum of 20 to 2000 Hz and an initial input level of 2 or $3g_{RMS}$. Vibrate for 5 minutes for this and each subsequent stress step.
2. Inspect and, if powered, operate the unit during and after each vibration.
3. Analyze all failures occurring during or after the vibration tests to determine whether the problem is design related or a latent flaw.
4. Increase input by $2g_{RMS}$ for successive vibration tests until tolerance limit is reached. The tolerance limit occurs when the unit does not function properly or at all and flaws are being induced into good hardware.
5. Establish the design capability or overstress region of the hardware (i.e., hardware which has weaknesses removed) based on failure analysis.
6. Use one-half of the design capability (g_{RMS}) as the initial screening level.

Ideally, the final vibration input screening level should be greater than or equal to one-half the design capability of the hardware and greater than the operating level or possibly even the design requirement. Figure 4-3 depicts this concept.

4.3 METHOD C - FAULT REPLICATION

Fault replication increases the screening input level until known faults in the unit being screened are precipitated. These known faults may be recognized manufacturing problems or faults that have been deliberately seeded. As in the case of Method B, use of this method must be approved by the government.

FIGURE 4-3. STEP-STRESS CONCEPT: RELATION OF ENVIRONMENTAL LEVELS



Method C can be used independently to establish a screening level or can be used in conjunction with Method B. In either case, the steps involved are similar to those listed for Method B except that the testing stops at the input level necessary to precipitate the known faults.

A minimum of ten faults should be available for replication to establish an effective screening level. Ideally, the faults should be "hidden" or latent, meaning that they would not be detected during functional tests. Representative faults to be used for seeding are:

- Loose hardware
- Flawed components (transistors, relays, etc.)
- Cold solder joints
- Nicked component mounting legs
- Incorrect bonding
- Removed bonding
- Intermittent switch
- Insufficient solder
- Connector or plug partially unseated
- Nicked wires
- Fractured hardware

4.4 METHOD D - HERITAGE SCREEN

A heritage screen is a starting screen derived from recent successful screening experience on equipment of comparable design and manufacture. Ideally, this experience would have been based on Method A. A heritage screen should only be considered if there are data substantiating its effectiveness. Government approval is required for use of Method D.

The baseline vibration profile in Table 3-3 is a heritage screen derived from general vibration screening experience. It can be used as a starting screen when it is not possible to perform a vibration survey.

SECTION 5
THERMAL CYCLING SCREEN DEVELOPMENT

The thermal screens in widest use today are (1) thermal cycling, (2) steady high temperature, and (3) thermal shock. The thermal cycling screen is recognized by the IES as being the most cost effective although the other two are used in some special situations.

The thermal screens described by the two methods herein, thermal survey and heritage, should be considered only as *starting* profiles. The effectiveness of any screen should be evaluated by engineering analysis of the equipment and the expected flaws, using factory and field failure data, and the failure history of the equipment during and subsequent to the screen, adjusting the screen parameters as the screen matures.

5.1 METHOD A - THERMAL SURVEY

A thermal screen is characterized by:

- Cycle characteristics
  - low temperature
  - high temperature
  - rate of change of temperature
  - dwell times at temperature extremes
- Equipment condition
  - powered or unpowered
  - monitored or unmonitored
- Number of cycles
- Level of assembly at which screen is performed

With the aid of a thermal survey, Method A tailors the cycle characteristics, equipment condition and number of cycles to the hardware to be screened.

THERMAL SURVEY PURPOSE

Developing a temperature cycling screening profile in terms of the thermal environment to which the hardware is to be subjected establishes:

- Hardware temperature history
  - temperature range
  - temperature extremes
  - stabilization criterion
  - soak time at temperature extremes
- Elements of the hardware to be subjected to this temperature history. It is generally not cost effective to perform a long cycle that subjects the entire mass of the item being screened to the temperature extremes. This is especially true with items (such as units, systems, and heavy modules) having high thermal inertia. Accordingly, the designer of the thermal cycling screening profile must decide what elements (such as parts, solder joints, PWA connectors) are important to be subjected to the specified hardware temperature history. This decision is based on where in the assembly the defects are expected to be precipitated by the screen. This could be, for example, in the semiconductor parts or in the PWA connectors.
- The method of heat transfer to the item being screened, such as:
  - coolant circulated through a coldplate thermally connected to the item
  - chamber air blown over the exterior of the item
  - conditioning fluid circulated through the item

To achieve a desired hardware thermal cycle, a certain temperature history of the heat transfer medium producing the thermal cycling is required. *A thermal survey evaluates the thermal response of various elements in the hardware to changes in the temperature of the heat transfer medium.* The temperature history of the heat transfer medium required to produce a desired hardware thermal response may then be developed.

THERMAL SURVEY GUIDELINES

Ideally, a thermal survey should include the following four steps. However, developing a computer simulation may not always be practical, affordable, or necessary.

1. *Perform a computer simulation.*

   Develop a detailed transient thermal model of the heat transfer occurring in the thermal cycling screening setup. (This is different from thermal analysis or thermal mapping, which is the measurement of the operating temperatures of the deployed equipment in actual use.) The model should be capable of predicting, as functions of the temperature history of the heat transfer medium, the temperature histories of the electronic parts, the PWAs, and other elements in the hardware targeted for removal of screenable defects. This model should simulate:

   - The dissipations of active parts in the hardware being screened (in the case of powered equipment)
   - The thermal resistances between locations within the hardware
   - The thermal resistances between locations in the hardware and the heat transfer medium
   - The thermal capacitances of the elements of the hardware

   Use the model to perform parametric analyses of the thermal responses of the elements in the hardware being screened to changes in the temperature of the heat transfer medium. The results of these analyses will be hardware and heat transfer medium temperature histories. These analyses will:

   - Identify the elements having the slowest thermal response to the heat transfer medium.
   - Evaluate the temperature rate of change of the heat transfer medium required to achieve the specified hardware temperature rate of change (a function of the velocity of the heat transfer medium).
   - Evaluate the dwell time of the heat transfer medium required for stabilization of the hardware temperatures (a function of the velocity and temperature of the heat transfer medium).

2. *Construct a replica of the actual screening facility. The thermal survey must be performed with a setup that replicates the thermal characteristics of the actual ESS setup in the following respects:*

   - Facility
   - Mounting of hardware in chamber
   - Powering (if powered during ESS)
   - Cooling (if powered and actively cooled during ESS)

3. *Instrument the important locations. Monitor and record the following quantities:*

   - Temperatures
     - hardware (the thermal analysis performed in the first step will aid the selection of hardware locations at which to measure temperature)
     - heat transfer medium, such as chamber air
     - coolants (if actively cooled)
   - Flow rates (velocities)
     - heat transfer medium, such as chamber air
     - coolants (if actively cooled)
   - Power dissipations (if powered)

   The hardware temperature histories typically are measured with thermocouples, which are point instruments (as distinguished from infrared thermography, with which a temperature map of an area is obtained). Data are obtained only at the preselected instrumentation locations, so it is important to instrument the important locations, with the aid of the computer simulation. Thermocouples must be electrically isolated from measurement surfaces that are electrically "hot."

4. *Perform the experimental thermal survey by completing the following three distinct procedures:*

   - The unit is soaked cold with power off until all thermocouples have stabilized at the test temperature, then power is turned on for the soak period, and then the rise to temperature at the required rate for the chamber. The chamber

temperature is held at the high temperature until all thermocouples have reached the test temperature. The data is used to establish the high temperature stabilization time.

- A similar cycle is run to establish the cold temperature stabilization time.
- Several complete cycles are run to fine tune the parameters to adjust for the shortened stabilization times.

In the same way as was done analytically in the computer simulation, measure the temperature histories as functions of the screening setup parameters. Perform at least three thermal cycles to establish a thermal steady state.

The results will be experimental plots used to establish the screening parameters required to achieve the specified hardware temperature histories. The analysis in the computer simulation should minimize the amount of iteration required in the laboratory to establish the screening setup parameters.

CYCLE CHARACTERISTICS

In characterizing the thermal cycle it is important to distinguish between the temperature histories of the hardware elements and that of the chamber air. The hardware temperature histories determine the effectiveness of the screen whereas the chamber air temperature history is the controlling element. To achieve a desired hardware temperature history, a certain temperature history of the chamber air producing the thermal cycling is required.

A thermal survey evaluates the thermal response of various elements in the hardware to changes in the temperature of the chamber air. The results of the thermal survey will be experimental plots of the thermal responses, measured at critical elements of the hardware, to changes in the temperature of the chamber air. The necessary temperature range and rate of change of the chamber air can then be identified for a desired response.

TEMPERATURE EXTREMES

The temperature extremes in a thermal cycle affect the effectiveness of the screen. The temperature range (the difference between the high and low temperatures) dictates the thermal stress/strain to which the hardware is subjected in each cycle. The number of cycles to failure varies inversely with the temperature range: the wider the range, the earlier the failure. By optimizing the temperature extremes, the screening profile designer can minimize the number of cycles required to precipitate flaws. Thus, the temperature extremes also affect the cost of the screen.

The key to selecting the temperature extremes is to stress the hardware adequately to precipitate flaws without damaging good hardware. In practice, temperature ranges from a minimum of 90°C to a maximum of 180°C have been used. Minimum values are: 125°C for modules (usually -50°C to 75°C), 110°C for units (usually -40°C to 70°C) and 100°C for systems (usually -40°C to 60°C). The following key factors should be considered for the extreme values:

- Storage temperature (high and low) limits of hardware such as the materials in printed wiring assemblies
- Maximum turn-on and operating temperatures of electronic parts

RATE OF CHANGE OF TEMPERATURE

The temperature rate of change affects the screening effectiveness in a complicated way. It also affects the duration and thus the cost of the screen.

The physical effect of the rate of change of temperature is quite complex. If a slab of material were heated and cooled uniformly, the thermal stresses and strains would be independent of the temperature rate of change.

In thermal stress screening, however the heating/cooling is nonuniform because of:

- Nonuniform heat transfer to the surface of the hardware
- Thermal lags between the surface and interior of the hardware
- Nonuniform thermal inertia of the various portions of the hardware

Consequently, instantaneous temperature gradients can exist throughout the hardware. These temperature gradients, and the resultant thermal stress/strains, increase with increasing temperature rate of change.

Consistent with this phenomenon, industry has found that increasing the temperature rate of change increases the screening strength up to a point. For example, the situation is more complicated for solder, which creeps at temperatures encountered in thermal stress screening. Creep, which has been identified as the major cause of solder joint failure, requires time to occur. If the temperature rate of change is too high, the thermal stress screening profile may actually be excessively benign for the purpose of precipitating defective solder joints to failure. (If properly conducted, environmental stress screening to precipitate defective solder joints in a specific set of equipment should have to be performed at only one level of assembly.)

If the chamber air temperature rate of change is too high, and/or if the dwell time is too short, and/or if the chamber air is too slow, then the part temperatures will not attain the chamber air temperature extremes. The result can be an unduly benign screen. This is illustrated by comparing Figures 5-1 and 5-2. In the first case, the air is fast enough and the dwell time long enough to enable the parts to stabilize and soak at the temperature extremes. In the second case, in which the air speed is six times slower and the dwell time one-sixth as long, the part temperatures do not stabilize, and instead cycle over a much smaller range than does the chamber air temperature. However, adequate experimentation and analysis can be used to tailor chamber conditions to achieve the desired temperatures and rates of change in the test items.

FIGURE 5-1. TEMPERATURE HISTORIES WITH HIGH CHAMBER AIR SPEED AND LONG DWELL TIMES

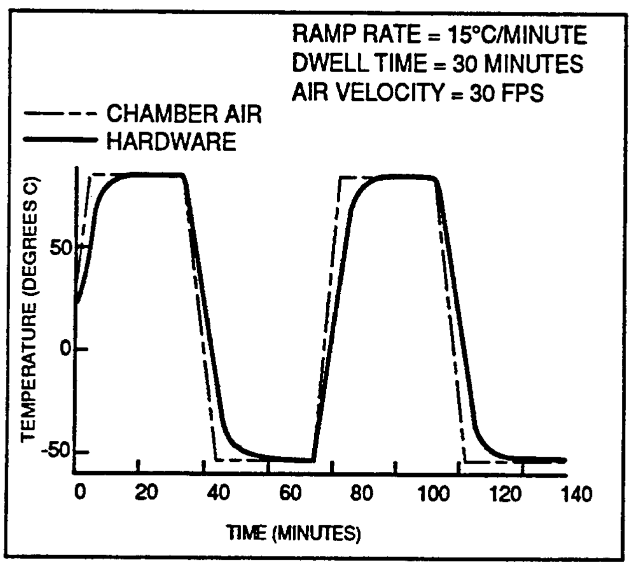
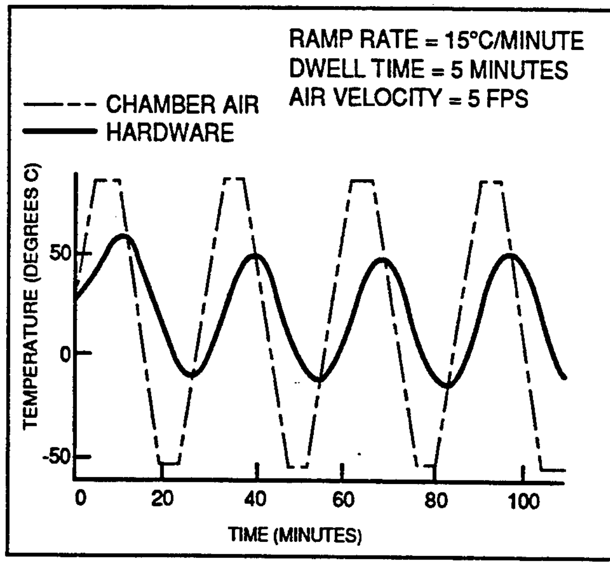


FIGURE 5-2. TEMPERATURE HISTORIES WITH LOW CHAMBER AIR SPEED AND SHORT DWELL TIMES



The choice of temperature rate of change depends on the nature of the hardware and the flaws expected. A high temperature rate of change is expected to be the most effective for precipitating flaws in such elements as plated-through holes, whereas a slow rate of change with long dwells at high temperature is expected to be the most effective for precipitating flaws in solder joints. In practice the temperature rate of change varies from 10°C/min to 20°C/min with the nominal values as follows:

PWA Screening	15°C/min to 20°C/min
Unit Screening	10°C/min to 20°C/min
System Screening	10°C/min to 15°C/min

The screening strength does not increase indefinitely with increasing temperature rate of change.

DWELL TIMES AT TEMPERATURE EXTREMES

The dwell time of the chamber air temperature consists of two elements, as shown in Figure 5-3:

- The time (D_1) required for the part temperatures to stabilize
- The additional time (D_2) required to "soak" the hardware at the temperature extremes

Stabilization Time

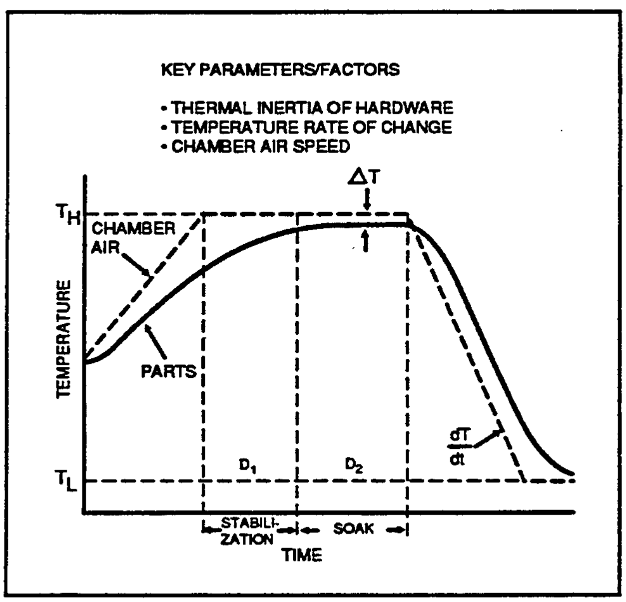
The stabilization time (D_1) required for internal components to reach the ultimate chamber temperature (chamber set point) has to be determined by the thermal survey. The choice of stabilization criterion affects the duration and thus the cost of the screen.

The recommended stabilization criterion is: *stabilization has occurred when the temperatures of the slowest-responding performance-related elements in the hardware being screened are within 15% (ΔT in Figure 5-3) of the ultimate temperatures.* During the screening of unpowered equipment, the ultimate temperatures are the chamber air high and low extremes as shown in Figure 5-2. With powered screening, the hardware temperatures may have other values, depending on the specifics of the equipment and the setup. The designer of the profile must decide which elements of the hardware being screened (excluding magnetics) are to be monitored.

Defining stabilization as the time required for the *rate of change* of the part temperatures to decrease to some small specified value is not recommended. Thermal analyses indicate that this criterion can result in excessively long-duration and thus expensive screens.

The stabilization time (D_1) for a specific screen, using the criterion recommended depends on the hardware being screened and the screening facility. The most important factors are the thermal inertia of the assembly being screened and the chamber air speed.

FIGURE 5-3. TYPICAL TEMPERATURE CYCLING PROFILES



Soak Time

The soak period (D_2) serves two purposes. First, this period allows solder to creep. The time required for solder to relax is on the order of 5 minutes. Second, for screens in which the equipment is powered and monitored, the soak periods at the temperature extremes enable functional testing to be performed to detect failures which do not manifest themselves at ambient temperature. The recommended values of the soak time (D_2) are as follows:

- Unmonitored equipment: 5 minutes
- Monitored equipment: long enough for functional testing to be performed or 5 minutes, whichever is longer.

EQUIPMENT CONDITION

Detection of failures induced by the environmental stresses generally requires that the equipment be powered and monitored. Testing the equipment to detect failures should be done during application of environmental stress screening, otherwise intermittent failures will go undetected. Testing only before or after stressing results in high risk of letting the intermittent flaws remain.

Thermal cycling differs from vibration in this respect: The period of a vibration cycle is a small fraction of a second and the duration of a vibration screen is on the order of 10 minutes. During a vibration screen, there is not enough time to fully test a complex system. In contrast, the period of a thermal cycle is on the order of hours and the duration of a thermal cycling screen is on the order of several hours. In a thermal screen, therefore, one can test the system at either or both temperature extremes as well as at ambient temperature.

When powered equipment is subjected to thermal cycling, the situation is complex because of the temperature rise produced by the dissipation (heat) of the electronic parts. The relation between the operating part temperatures and the chamber air temperature depends on the specific equipment and the screening parameters. In addition to the instantaneous thermal

gradients occurring in screens of unpowered equipment, additional thermal gradients occur because of the flow of heat from the dissipating parts to the surroundings.

Some factors involved in deciding whether or not to have the equipment operating are as follows:

- A powered screen is more effective in precipitating flaws than an unpowered screen. Powering produces temperature gradients in the hardware not present in unpowered equipment. The thermal stresses/strains resulting from these thermal gradients may precipitate flaws that escape in unpowered screens.
- A powered and monitored screen may detect failures that escape in an unpowered screen (intermittent failures). Failures that do not manifest themselves in testing at ambient conditions may show up in testing at high or low temperature or during vibration. An example is a broken connection in which the pieces are touching just enough to provide continuity in the absence of thermal/vibration stresses.
- A powered and monitored screen is more expensive than an unpowered screen.
- A power-off screen at the PWA level of assembly is often used as an effective screen for latent part defects. However, it should only be considered if the PWA will see a powered screen at the next higher level of assembly.

Although details will differ for any specific item to be screened, the consensus of industry experience on the basis of technical and cost trade-off considerations is as follows:

ASSEMBLY LEVEL	EQUIPMENT CONDITION
Board	Unpowered
Unit	Powered monitored
System	Powered monitored

NUMBER OF CYCLES

As do the cycle characteristics, the choice of the number of cycles impacts the effectiveness and the duration and thus the cost of the screen.

In evaluating the effect on failure of the number of cycles, it is important to distinguish between fallout at the point of screening and subsequent failures at higher levels of assembly and in the field. ESS takes life out of good and bad equipment although the decrease in the useful life of good equipment is small with a well designed screening profile. The number of failures occurring per cycle usually begins low, rapidly increases, then decreases exponentially until stabilization. When stabilization occurs, usually an optimum number of cycles has been reached.

Thermal cycling produces thermal stresses which induce alternate expansion and contraction. The stresses and strains are highest at flaws because each flaw creates a stress riser that allows the stress to precipitate a flaw (i.e., latent defect) to hard (i.e., detectable) failure. The cyclic loading causes the flaws to grow. Eventually they become so large that they cause a complete structural failure and thus an electrical failure. For example, a cracked plated through hole eventually cracks completely around and causes an open circuit.

The lifetime of the product is governed by the number of cycles, that is, the number of stress/strain reversals. The number of cycles to failure is a decreasing function of the stress/strain range per cycle, which in turn is a monotonically increasing function of the temperature range per cycle. However, a properly designed thermal screen will precipitate failures in flawed items, while not consuming a significant portion of the useful life of good items.

For solder, the physics of failures induced by thermal cycling is more complex than for materials such as aluminum and copper. The reason is that, at the temperatures encountered in electronics equipment, solder creeps. Creep has been identified as the major cause of solder joint failures. Solder creeps at a rate that increases with increasing temperature. Consequently, the number of cycles to failure of solder joints depends on other parameters as well as temperature range. The most severe thermal cycles for solder are those in which creep has sufficient time to occur. However, a screen should avoid unnecessarily inducing creep in solder joints.

Although the selection of the number of thermal cycles is critical relative to the effectiveness and cost of the screen, the procedure to do so is controversial. What is recommended here is a practical empirical approach instead of estimating the residual fault con-

tent of an item and a corresponding screening strength necessary for an acceptable product.

The number of cycles varies with product complexity, design and process maturity and whether the other thermal screen characteristics have been carefully chosen. The recommended procedure for selecting the number of cycles is:

1. Be sure that the thermal survey and analyses have been completed to identify the most appropriate values of temperature range (high and low value), product and chamber temperature rate-of-change, dwell times, and whether powered and monitored.

2. Based on the above, select the initial number of cycles for the thermal screen from the following ranges:

PWA	20 to 40 cycles
Unit/System	12 to 20 cycles

3. Perform thermal screen as planned. Record when failures occur, types of failures, and corrective actions taken to prevent reoccurrence. Plot failures as a function of temperature cycle. When stabilization occurs in above plot, reduce the screen number of cycles to value corresponding to stabilization.

4. Continue monitoring screen results to justify any other adjustments of screening cycles, either up or down, that may be warranted.

5.2 METHOD B - HERITAGE SCREEN

Similar to the Heritage Screen for Random Vibration discussed in Section 4, the Heritage Thermal Screen would be one derived from past, successful, screening experience on equipment of comparable design and manufacture. Again, this should be an iterative process where the fallout, or flaw precipitation results, are carefully monitored so that screening strength can be adjusted to the most cost effective value as discussed in Method A.

A comparable approach to the Heritage Screen that is based on general thermal cycling results in the Baseline Thermal Screening profile given in Section 4. The Baseline approach is presented as a starting screen to be used when it is not possible to use Method A or no data are available for the Heritage screen. It is more important with the Baseline approach that the results be monitored and the screening strength be adjusted as necessary. Government approval is required for use of either the Heritage or the Baseline Thermal Screen.

APPENDIX A
GLOSSARY & DEFINITIONS

A.1 GLOSSARY

ASD	Acceleration Spectral Density
ESS	Environmental Stress Screening
FRACAS	Failure Reporting, Analysis and Corrective Action System
IC	Integrated Circuit
IES	Institute of Environmental Sciences
NDI	Nondevelopment Item
IRIG	Inter-Range Instrumentation Group (a U. S. Government Agency)
OEM	Original Equipment Manufacturer
OTS	Off the Shelf
PWA	Printed Wiring Assembly
R&M	Reliability and Maintainability
RAM	Reliability, Availability and Maintainability
RFP	Request for Proposal
RMS	Root Mean Square
SRU	Shop Replaceable Unit
SOW	Statement of Work
SPC	Statistical Process Control
TAAF	Test, Analyze & Fix
TDP	Technical Data Package

A.2 DEFINITIONS

Assembly	A combination of parts joined together to perform a specific function.
Burn-In	Burn-in is usually applied during production at the end item level only and consists of an operational period for a specified number of hours with a specified failure-free period. The operational conditions and environmental stresses in most cases attempt to simulate field conditions and therefore usually are the same as the test conditions used for demonstrating reliability. Burn-in is normally performed on 100 percent of the items in each production lot.
Design Capability	The level of stress (*thermal* or *mechanical*) which an item is able to achieve or endure without damage or significant reduction of its overall usable life.
Environmental Stress Screening	Environmental stress screening of a product is a process which involves the application of one or more specific types of environmental stresses for the purpose of precipitating to hard failure, latent, intermittent, or incipient defects or flaws which would cause product

	failure in the use environment. The stress may be applied in combination or in sequence on an accelerated basis but within product design capabilities.
Failure Mode	The fundamental physical or chemical process responsible for a failure; the causative agents of a failure, including circumstances during design, manufacture or use that may lead to a failure.
Hermeticity	The ability of a sealed item to remain impervious to outside contaminants.
Indenture Level	Level of assembly; the highest indenture level is a *system*, the lowest is a *part.*
Infant Mortality	Failures that occur early in the life of the unit.
Isolation	The reduction in severity of response, force, or motion to input stimulus.
Latent Defect	An inherent or induced weakness, not detectable by ordinary means, which will either be precipitated to early failure under ESS conditions or eventually fail in the intended-use environment.
Module	A self-contained collection of chassis-mounted components and/or printed wiring assemblies within one package which performs a specific function or group of functions, and which is removable as a single package from an operating system.
Part	Any identifiable item within the product which can be removed or repaired (e.g., discrete semiconductor, resistor, integrated circuit, connector); used interchangeably with *piece part*, *component part*, and *device.*
Parts Rescreening	Usually refers to all microcircuits and semiconductors at receiving inspection being tested to specification and environmental requirements.
Patent Defect	An inherent or induced weakness which can be detected by inspection, functional test, or other defined means without the need for stress screens.
Precipitation of Defects	The process of transforming a latent (*undetected*) defect into a patent (*detected*) defect through the application of stress screening.
Printed Wiring Assembly	An assembly containing a group of interconnected components mounted on a circuit card. Comparable terminology includes printed circuit board and printed circuit assembly.
Screening Effectiveness	Generally, a measure of the capability of a screen to precipitate latent defects to failure; sometimes used specifically to mean screening strength.
Screening Strength	The probability that a specific screen will precipitate a latent defect to failure, given that a latent defect susceptible to the screen is present.
System	A group of units interconnected or assembled to perform an overall function.
Transmissibility	The ratio of output response to input motion.
Unit	A group of modules interconnected or assembled to perform a specific function with a system.

APPENDIX B
REFERENCES

B.1 MILITARY

1. Air Force Pamphlet 800-7, "USAF R&M 2000 Process"

   This is the Air Force document which forms the basis for the Air Force R&M program. ESS is given visibility in a detailed appendix, with specific parameters for temperature cycling and random vibration included in a chart titled "R&M 2000 Baseline Regimen."

2. Army Materiel Command (AMC) Regulation 702-25, "AMC Environmental Stress Screening Program"

   This Army Regulation is the basis for ESS requirements in the Army. This regulation contains a Baseline Regimen and requires that a FRACAS be implemented. Appendix A contains a baseline Statement of Work to be used in Invitations for Bids, Requests for Proposal, and awarded contracts.

3. DoD 4245.7-M, "Transition from Development to Production"

   This document provides an excellent overview, in the Manufacturing Screening template, of the proper way to use ESS. The Manufacturing Screening template also places strong emphasis on keeping ESS dynamic and flexible through intelligent tailoring.

4. DoD-HDBK-344 (USAF) "Environmental Stress Screening of Electronic Equipment"

   This handbook covers a variety of important issues, including contractual aspects, planning for development and production phase ESS, and incorporating results of different program test phases. This handbook also contains a mathematical methodology for developing a screen.

5. DoD Directive 5000.1, "Defense Acquisition"

   This directive describes the policies which govern defense acquisition by DoD components, the major characteristics of the three decision making support systems affecting acquisition, and the acquisition responsibilities of key officials and groups. Although the directive doesn't mention ESS, it does emphasize developing reliable systems, which is the goal of ESS.

6. DoD Instruction 5000.2, "Defense Acquisition Management Policies and Procedures"

   This instruction describes the procedures to be used for translating broadly stated mission needs into stable, affordable, DoD acquisition programs. It emphasizes effective acquisition planning, improved communications with users, and aggressive risk management by both Government and industry. The reliability and maintainability section (Part 6, Section C) requires that an aggressive ESS program be developed for electronic equipment and applied to engineering development and production assets.

7. MIL-HDBK-338-1A, "Electronic Reliability Design Handbook," Volume I

   This handbook, which covers all aspects of reliability program planning and execution, has a section on assembly-level ESS. The assembly-level ESS section contains a realistic approach for determining appropriate screens based on thermal and vibration surveys. The need for tailoring, continuous reevaluation of screen cost-effectiveness, and understanding root causes of failures are continuously emphasized.

8. MIL-HDBK-727, "Design Guidance for Producibility"

   This handbook, which covers all aspects of producibility, has a section on part screening. Although this tri-service ESS Guidebook does not discuss Part Screening, an ESS practitioner who has the need for a detailed discussion of Part Screening may refer to MIL-HDBK-727.

9. MIL-HDBK-781, "Reliability Test Methods, Plans, and Environments for Engineering Development, Qualification and Production"

   Although this is a handbook which was developed for Reliability Testing, there is a section which describes three methods for monitoring ESS (the Computed ESS Time Interval Method, the Graphical Method and the Standard ESS Method).

10. MIL-STD-781, "Reliability Testing for Engineering Development, Qualification, and Production"

    This Military Standard, although developed for Reliability Qualification Testing, Reliability Growth Testing, etc., contains a Task for implementing Environmental Stress Screening in contracts.

11. MIL-STD-785, "Reliability Program for Systems and Equipment, Development and Production"

    This Military Standard provides general guidance and specific tasks for reliability programs during the development, production, and initial deployment of systems and equipment. Task 301 of MIL-STD-785 provides specifics for specifying an ESS program in contracts.

12. MIL-STD-1235, "Single-and Multi-Level Continuous Sampling Procedures and Tables for Inspection by Attributes"

    This standard provides tables and procedures for applying five different types of continuous sampling plans for inspection by attributes.

13. NAVMAT P-9492, "Navy Manufacturing Screening Program"

    This is the "grandfather" of all current ESS standards and documents. This document contains a Baseline ESS Regimen which has been extensively implemented on U. S. Navy programs. This document also defines temperature change rates in terms of equipment response instead of chamber air conditions.

14. NAVSO P-6071, "Best Practices"

    NAVSO P-6071, a companion to DoD 4245.7-M, offers a very useful executive-style summary of the important issues associated with successfully using ESS. This summary is accompanied by a unique chart that contrasts the traps and consequences of some current approaches with the potential benefits of applying the Best Practices strategies.

15. RADC-TR-86-149, "Environmental Stress Screening"

    This technical report, developed by Rome Laboratories, contains quantitative techniques for planning, monitoring and controlling the cost effectiveness of stress screening programs for electronic equipment. A method of estimating the number of defects remaining in the delivered product is also provided.

16. RADC-TR-87-225, "Improved Operational Readiness through Environmental Stress Screening"

    This technical report, developed by Rome Laboratories, contains guidelines for the application of ESS to field inventory hardware. Methods are presented for the selection of equipment for ESS application which offer significant potential for operational readiness improvement and life cycle cost reduction.

17. RADC-TR-90-269, "Quantitative Reliability Growth Factors for ESS"

    This technical report, developed by Rome Laboratories, examines the measured field reliability improvements resulting from multiple cycle ESS on avionics systems. For several systems, additional cycles of ESS were applied. Through the comparison of the serialized field reliability records for those systems with and without the additional ESS cycles, an assessment of the improvement in field MTBF resulting from ESS was made.

18. Sacramento Air Logistics Center (SM-ALC), "Environmental Stress Screening Handbook"

    This document was developed to provide program managers and engineers information on "how to set up an ESS program." This handbook considers often overlooked administrative as well as technical concerns such as previous contractor experience, decision criteria for ESS applicability, cost effectiveness in the production process, and contractor development of appropriate ESS methodologies.

19. TE000-AB-GTP-020A, "Environmental Stress Screening Requirements and Application Manual for Navy Electronic Equipment"

    This document, developed by Naval Sea Systems Command (NAVSEA), contains the basis for the NAVSEA ESS program. It is intended for use by Navy program managers as the baseline minimum ESS requirements for Statements of Work, and by design and manufacturing engineers and depot repair facilities for implementation. It contains specific information on determining the natural frequencies and displacements of PWAs. It also contains guidance on understanding the equipment's vibration and thermal responses.

20. Tri-Service "Technical Brief for TAAF Implementation"

    This document was developed by the three services in an effort to have a unified understanding of the TAAF process. This document provides in a single, concise source document the methods most likely to result in a successful TAAF program

B.2 INDUSTRY

1. Institute of Environmental Sciences, "Environmental Stress Screening Guidelines, 1981"

    This was the first ESS Guidelines document prepared by the Institute of Environmental Sciences. This document, which was developed by ESS practitioners from industry and Government, provides technical information on Piece-Part Screening as well as Module, Unit, and System Level Screening.

2. Institute of Environmental Sciences, "Environmental Stress Screening Guidelines for Assemblies, 1984, 1988"

    This document was developed by the Institute of Environmental Sciences as an update to the 1981 Guidelines document and provides detailed information on module, unit and system level screening.

3. Institute of Environmental Sciences, "Environmental Stress Screening Guidelines for Assemblies, 1990"

    This document differs markedly from the 1981, 1984, and 1988 IES Guidelines documents in that it is procedural and tutorial in nature. This document incorporates the results of research conducted during the 1980s on the physical processes involved in ESS. The Guidelines include program management guidance, cost-effectiveness analysis techniques, descriptions of vibration and thermal survey methodologies, and ESS tailoring principles.

4. Institute of Environmental Sciences, "Environmental Stress Screening Guidelines for Parts, 1985"

   This document addresses part screening methods, development of a screening or rescreening program, case histories and screening results data. Also provided is an extensive treatment of integrated circuit packaging technology, a subject which is important to anyone involved in piece part ESS.